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BLAST LOADING IN EXISTING STRUCTURES - BASEMENT MODELS

George A. Coulter

Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

August 1972

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by

George A. Coulter

August 1972

U.S. ARMY ABERDEEN RESEARCH AND DEVELOPMENT CENTER
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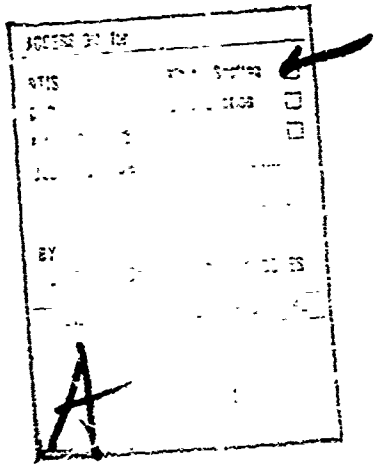

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13. ABSTRACT

Experimental results are given for the effects of shock wave induced interior flows on small objects placed inside a 1/12th scale basement shelter. Pressure-time records and high speed photographs of the internal air flows created by exposure to outside shock overpressures of 5, 10 and 20 psi are presented. Flows down the inside stairway into the model were found to create a large scale circular motion around the room. Cross-the-floor components of velocity caused by these flows are given for the motion of the various objects placed inside the model.

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MEMORANDUM REPORT NO. 2208

AUGUST 1972

BLAST LOADING IN EXISTING STRUCTURES - BASEMENT MODELS

George A. Coulter

Terminal Ballistic Laboratory

Progress Report to Office of Defense Civil Prepardness Agency
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B A L L I S T I C R E S E A R C H L A B O R A T O R I E S

MEMORANDUM REPORT NO. 2208

GACoulter/mba
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August 1972

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Experimental results are given for the effects of shock wave induced interior flows on small objects placed inside a 1/12th scale basement shelter. Pressure-time records and high speed photographs of the internal air flows created by exposure to outside shock overpressures of 5, 10 and 20 psi are presented. Flows down the inside stairway into the model were found to create a large scale circular motion around the room. Cross-the-floor components of velocity caused by these flows are given for the motion of the various objects placed inside the model.

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I. INTRODUCTION

Initial results obtained from a 1/12th scale model of a basement shelter were reported from a study of the interior blast created flows obtained from the BRL 24-inch Shock Tube. The experiments were designed to simulate the flows and loading within a 100 person basement shelter when the above-ground floors have been removed by the incoming blast wave.

Earlier results obtained by a smoke tracer method from two-dimensional models indicated downward directed flows from the entrance. These results tend to be verified by the pressure-time records obtained from the present three-dimensional 1/12th scale model. In addition, low pressure vortex regions were measured from positions near the open stairway within the model.

A second phase of the experiments consisted of photographing with a high speed camera the flow-induced motion of linear scaled (1/12th) OCD survival packages placed within the basement model. The density of the scaled objects was left the same as the full-size packages.

This report shows pressure-time histories from various interior positions of the model, selected prints of frames from the high-speed photographs (Fastex at about 3000 PPS), calculations of average component velocities of some of the objects placed inside the model, and post-shot still photographs to show the final object placement after motion has stopped.

II. EXPERIMENTS

The results from the two-dimensional model reported in BRL Memorandum Report No. 2118 indicated strong downward directed flows when the shock waves entered overhead. The object of the first part of the present experiments was to measure the interior pressures which were indicated by the two-dimensional results. This was done with pressure probes using a three-dimensional model with a stairway as the entrance to the basement. During the second part of the experiments, the

pressure probes were removed and small objects were placed inside the model. High speed photography was then used to observe the motion of the objects as the shock wave entered down the stairway.

A. Pressure Measurements

The 1/12th scale model of a 100 person basement shelter which was used during the experiments is shown in Figures 1 and 2. The orientation to the shock wave is as shown with the shock wave moving down the stairs. The transducer locations are shown in Figure 2. The front of the pressure probes were positioned two inches above the floor, facing toward the stairs, and at the positions shown. The side-on pressure transducers were mounted two inches to rear of positions as shown, flush with the floor. Positions 1 and 1-A transducers were used as pressure monitors from shot to shot.

Susquehanna Instrument Model ST-2 transducers were used in both the flush positions and the probes. These piezoelectric transducers were coupled through Kistler Model 566 charge amplifiers to a Bell and Howell tape machine, Model VR-3300.

B. Photographic Recording

For the photographic phase the pressure transducers were removed except for one transducer to monitor the pressure at the center of floor. Small objects were made to 1/12th the linear scale of several OCD Survival Packages. These are listed in Table I with pertinent information. Pictures were taken of the motion of three of the nylon cylinders exposed to input shock overpressures of 5, 10 and 20 psi at several locations inside the model. Figure 3 shows these locations. The total number of objects were then stacked together to simulate possible storage positions of the OCD Survival Packages. Figure 4 shows the stacking and positions used.

The motion of the objects was observed through a window in the end of the model away from the stairway. A 16mm Fastex camera operated at about 3000 PPS slowed the motion sufficiently for observation. Five 500 watt photoflood lamps (DXC) placed very close to the glass windows gave sufficient light to record on either Tri X or on Extachrome 7242

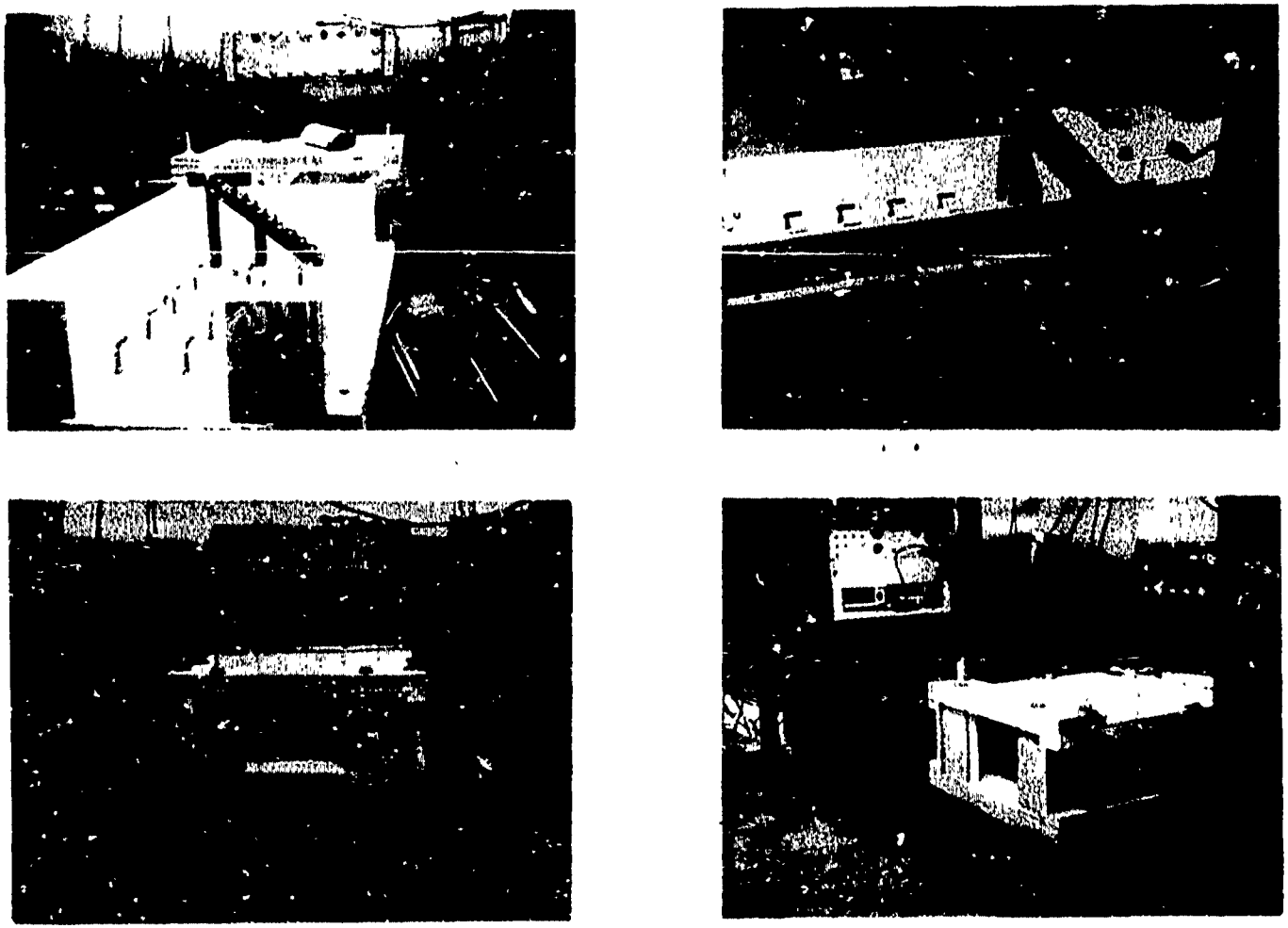


Figure 1. 1/12th Scale Basement Model

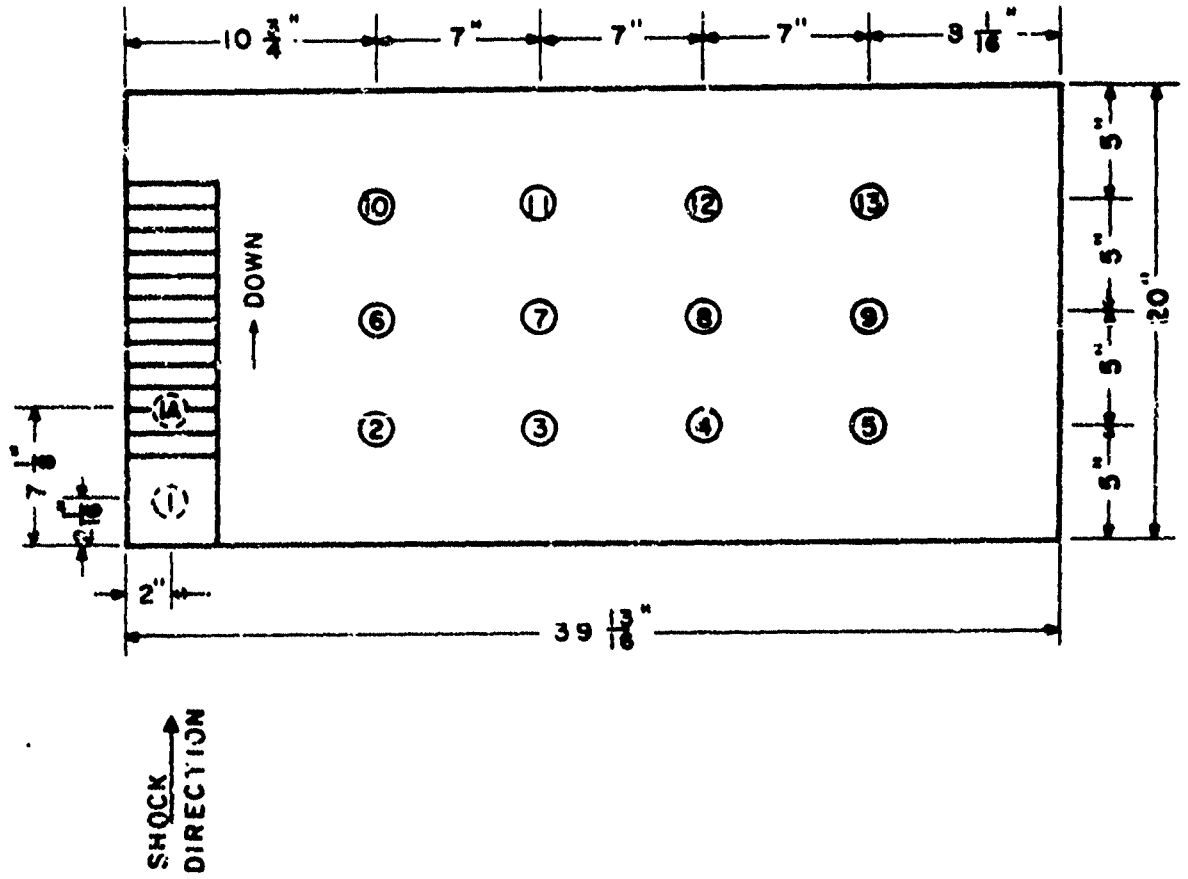


Figure 2. Gage Positions Model 40

Table I. Model OCD Survival Packages

Objects	Code	Quantity	Size, Inches	Mtl	Av. Wt, oz	Av. Density, lb/ft^3
Pedal Ventilator Kit	A	1	1.44 x 3.15 x 4.98	Styrefoam	0.67	3.2
Kearny Pump Kit (Box A)	B	1	0.46 x 3.50 x 2.65	Styrefoam	0.14	3.2
Kearny Pump Kit (Box B)	C	1	0.46 x 0.46 x 7.85	Cork	0.16	12
Circular Water Container (Box A)	D	1	0.53 x 1.60 x 2.00	Cork	0.19	12
Circular Water Container (Box B)	E	1	1.04 x 2.04 x 1.04	Cork	0.28	12
Dual Purpose Container (with drinking water)	F	4	1.33 x 1.48 x 1.33	Oak	1.06	44
Sanitation Kit-SK IV	G	2	1.38 D x 1.81	Balsa	0.16	6.3
Water Drums	H	4	1.28 D x 1.83	Nylon	1.56	71
Survival Biscuits	I	6	0.81 x 1.18 x 1.60	White Pine	0.37	26
Radiation Kit	J	2	0.88 x 0.90 x 1.35	Cork	0.12	12

NOTE - Model objects are 1/12th linear size of Survival Packages.

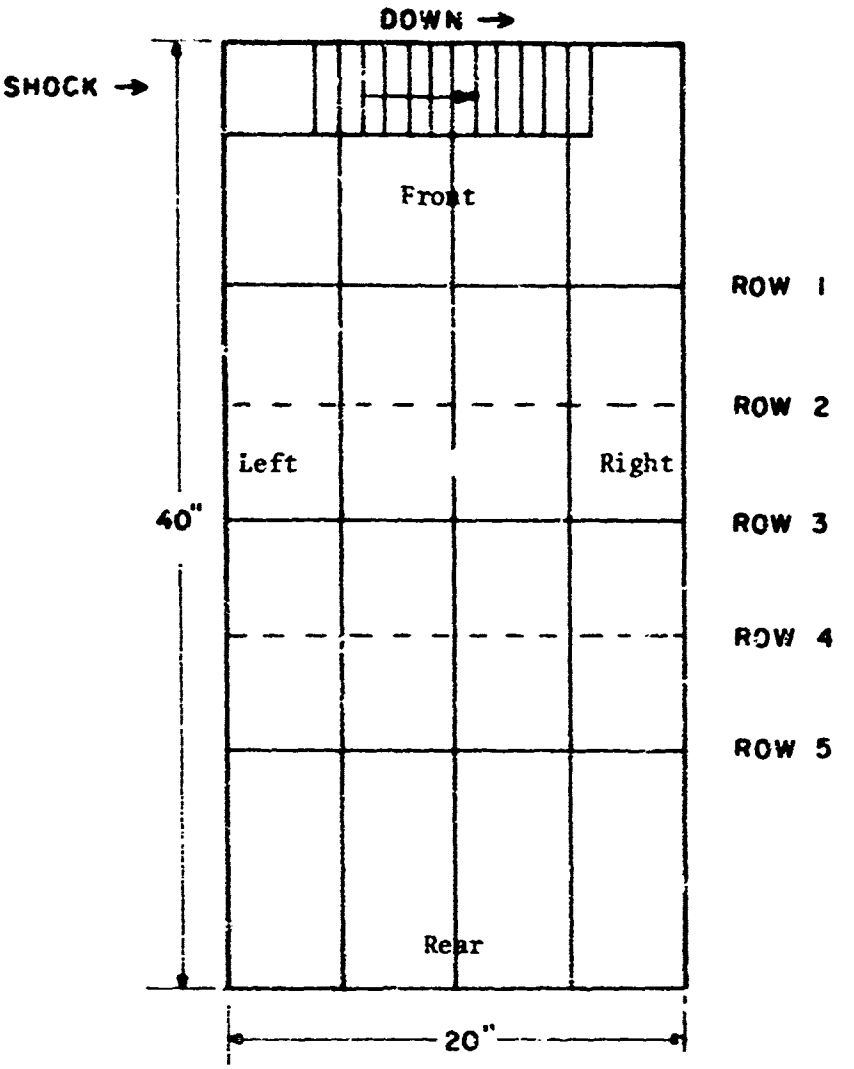
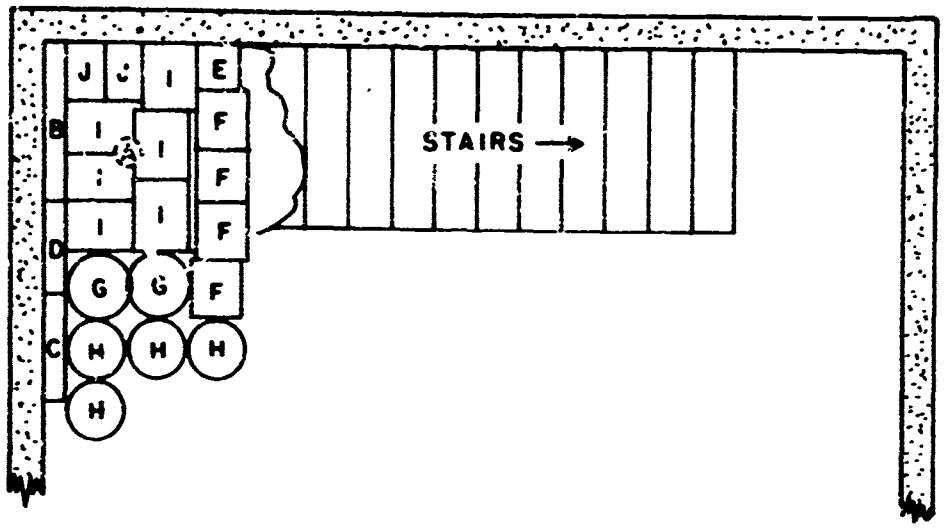
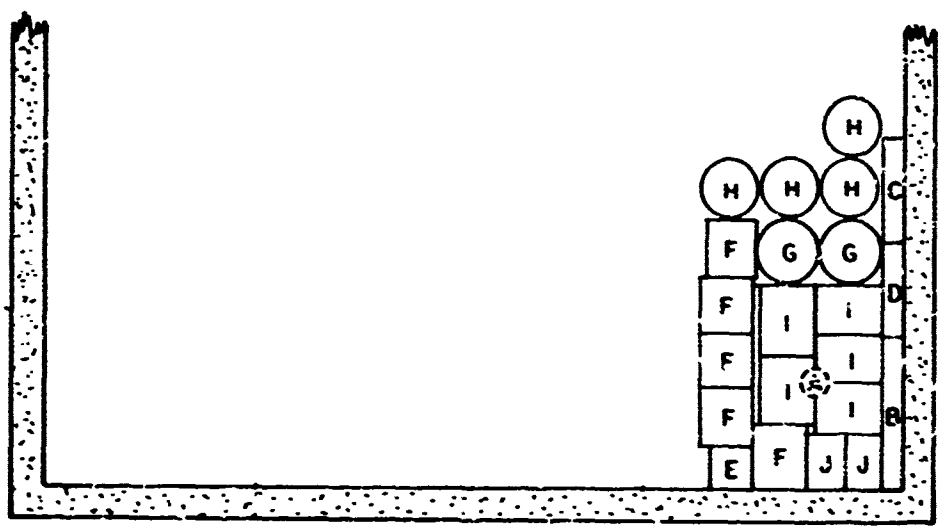


Figure 3. Floor Plan for Cylinder Experiments

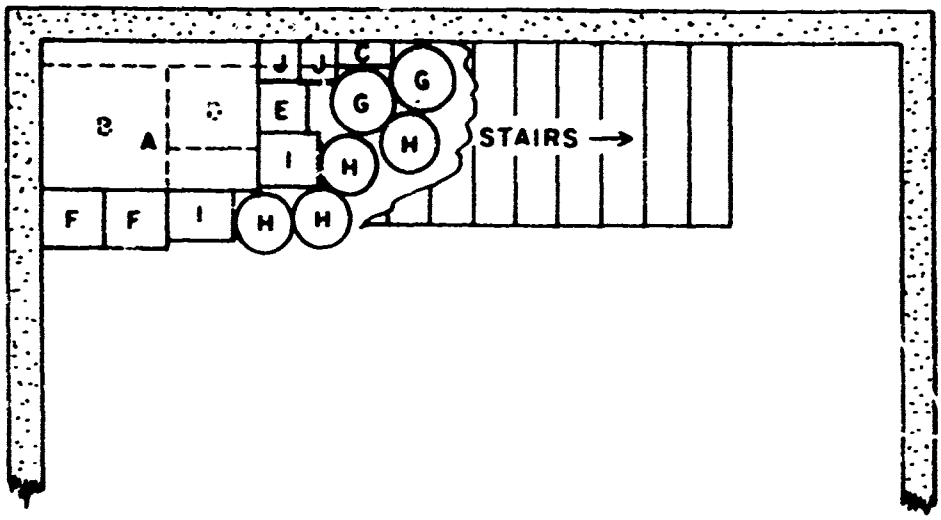


POSITION 1

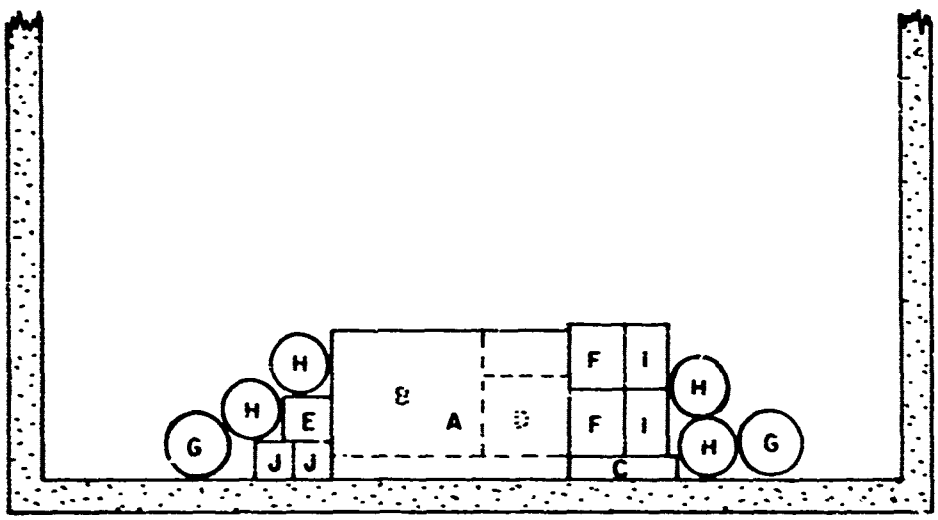


POSITION 2

Figure 4. Positions for Model Survival Packages

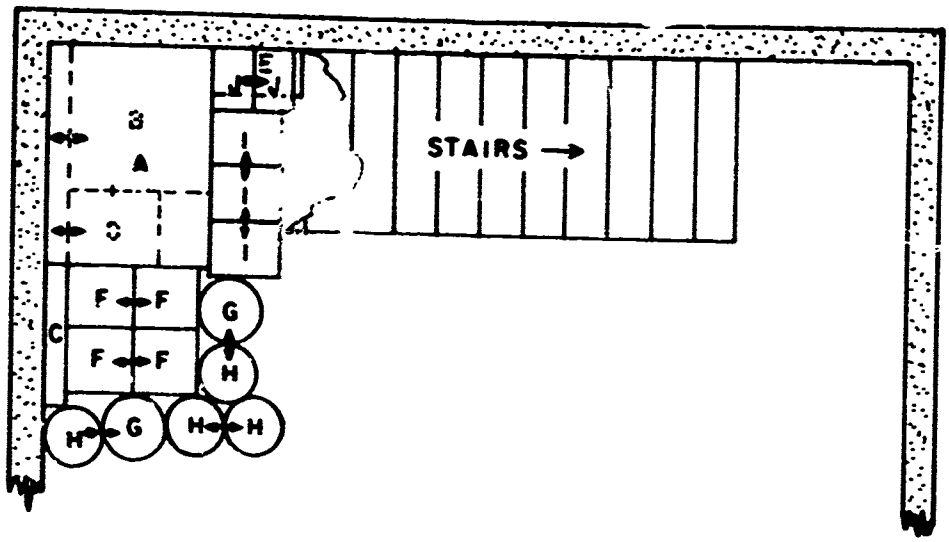


POSITION 3

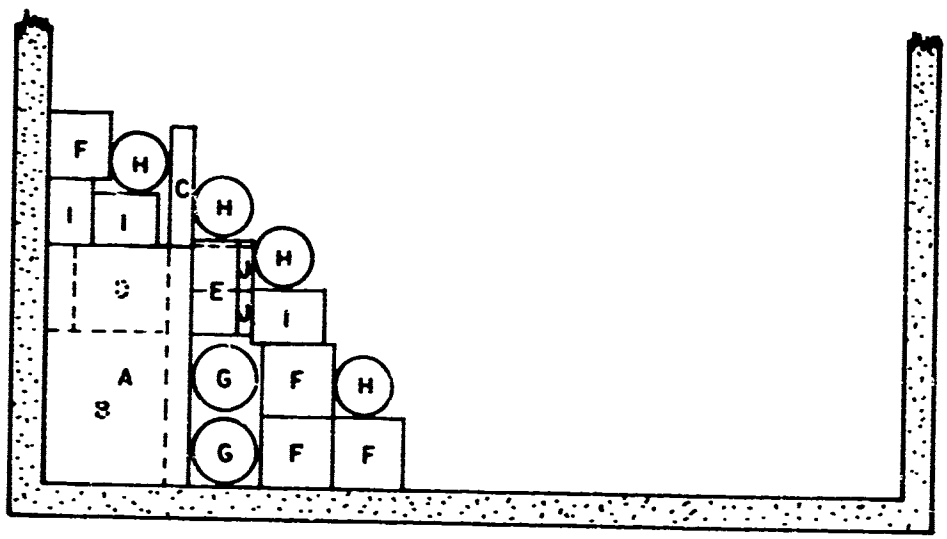


POSITION 4

Figure 4. (Continued)



POSITION 5



POSITION 6

Figure 4. (Continued)

color film if the developing were increased for the color film.

Still photographs of starting positions and end locations are presented in the Results Section along with prints of selected frames from the 16mm films to illustrate the motion of the small scaled objects.

III. RESULTS

The experimental results are presented as pressure-time records in Appendix B and as selected frames from the high speed films, shown in Appendix D.

A. Pressure-Time Records

Table A-I, Part A (Appendix A) lists information pertinent to the pressure transducers' locations, the ambient conditions, and descriptions of the observed waveforms. Figure 5 shows pressure-time records obtained from the front row probe positions for a shock wave of 5 psi outside the model entrance. Pressure-time records from other positions are shown in Appendix B. A study of the traces show several characteristics. (1) The traces from positions nearest the stairway showed large pressure dips between 3 and 5 milliseconds with the largest dips recorded near the bottom of the stairway. These dips probably indicate the presence of low pressure vortices from the stairwell edges. (2) Some of the positions (such as (1)) gave traces with quite large pressure peaks indicating probably reflections of the shock wave from the walls of the basement model. (3) Records from positions near the center of the floor showed most nearly ideal smooth fill records indicating a lack of both vortices and reflections. Figure 6 displays the results of the BRL room fill predictions with experimental data observed at the center of the floor. There is a slight displacement of the data from zero time (entrance of shock wave onto stairs) due to the arrival time of the diffracted shock at the center of the room. An entrance choking parameter and a plot routine (Figure 7) have been added to the program as reported in BRL Memo Report No. 1987, June 1969. The sonic fill case also has been included (see Figure 6-C at the beginning of the curve)

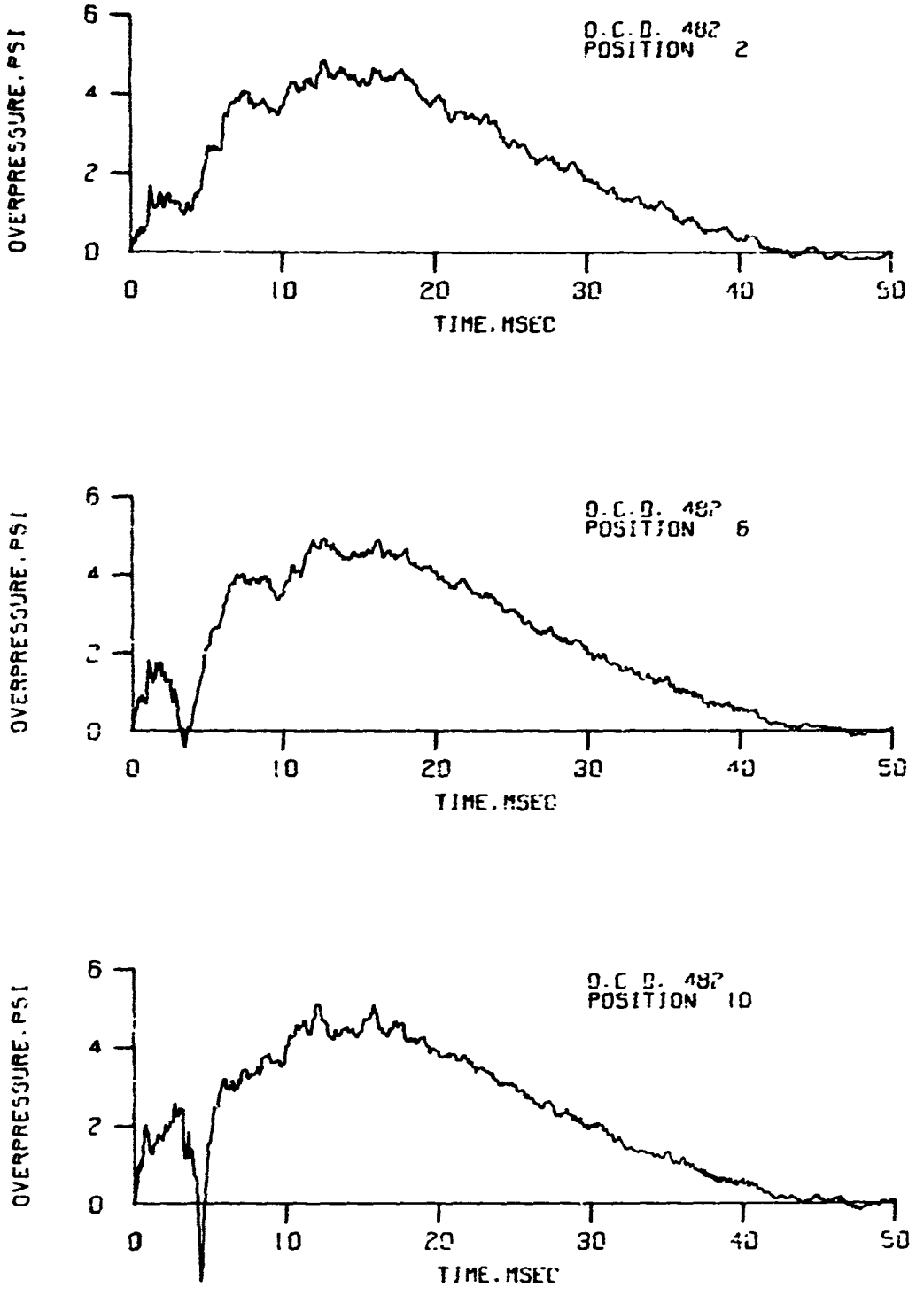
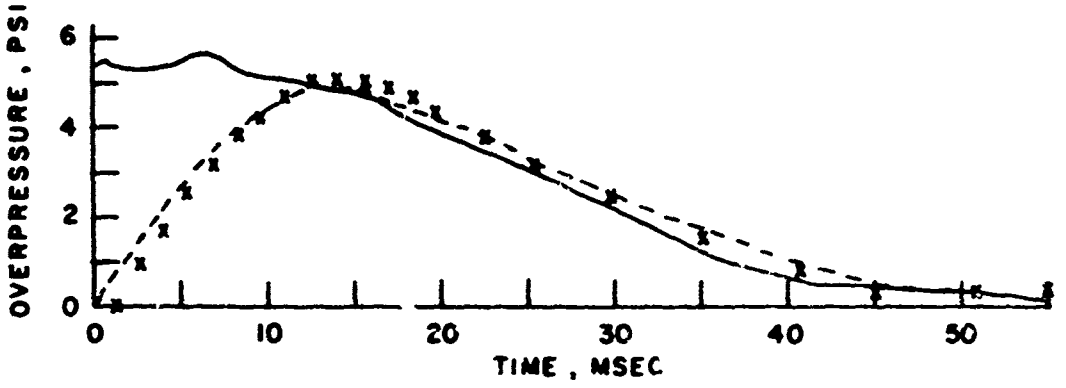
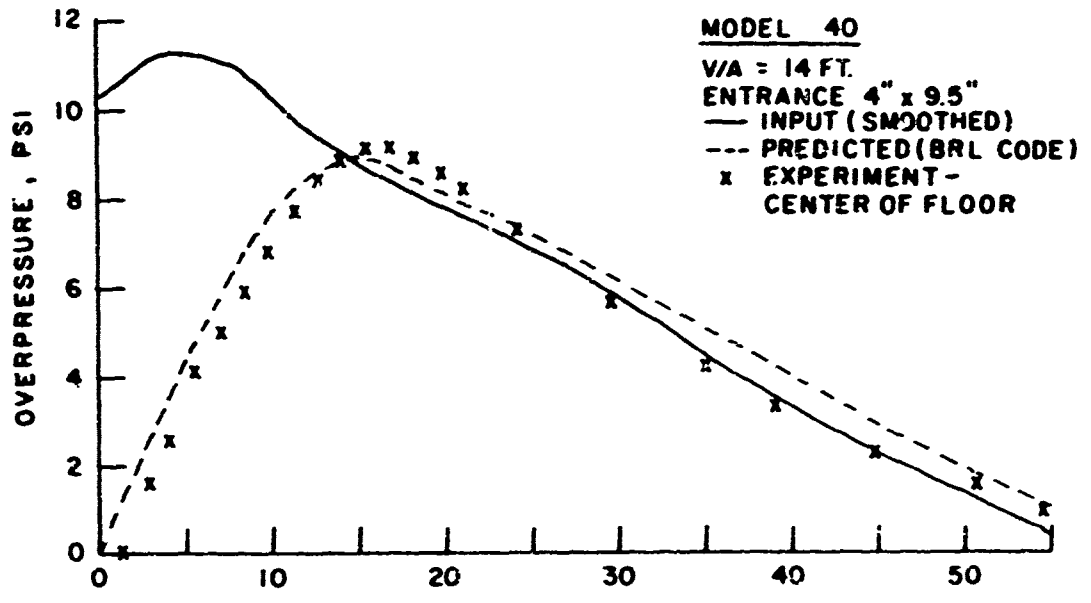


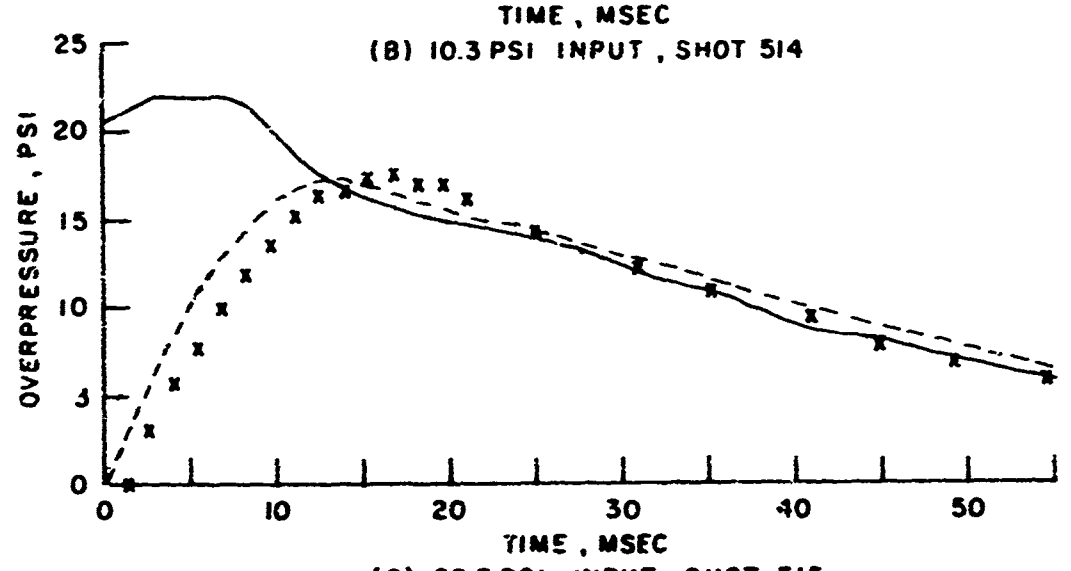
Figure 5. Records from the Pressure Probes - Ps = 5psi



(A) 5.4 PSI INPUT , SHOT 513



(B) 10.3 PSI INPUT , SHOT 514



(C) 20.5 PSI INPUT, SHOT 515

Figure 6. Pressure-Time Fill Predictions

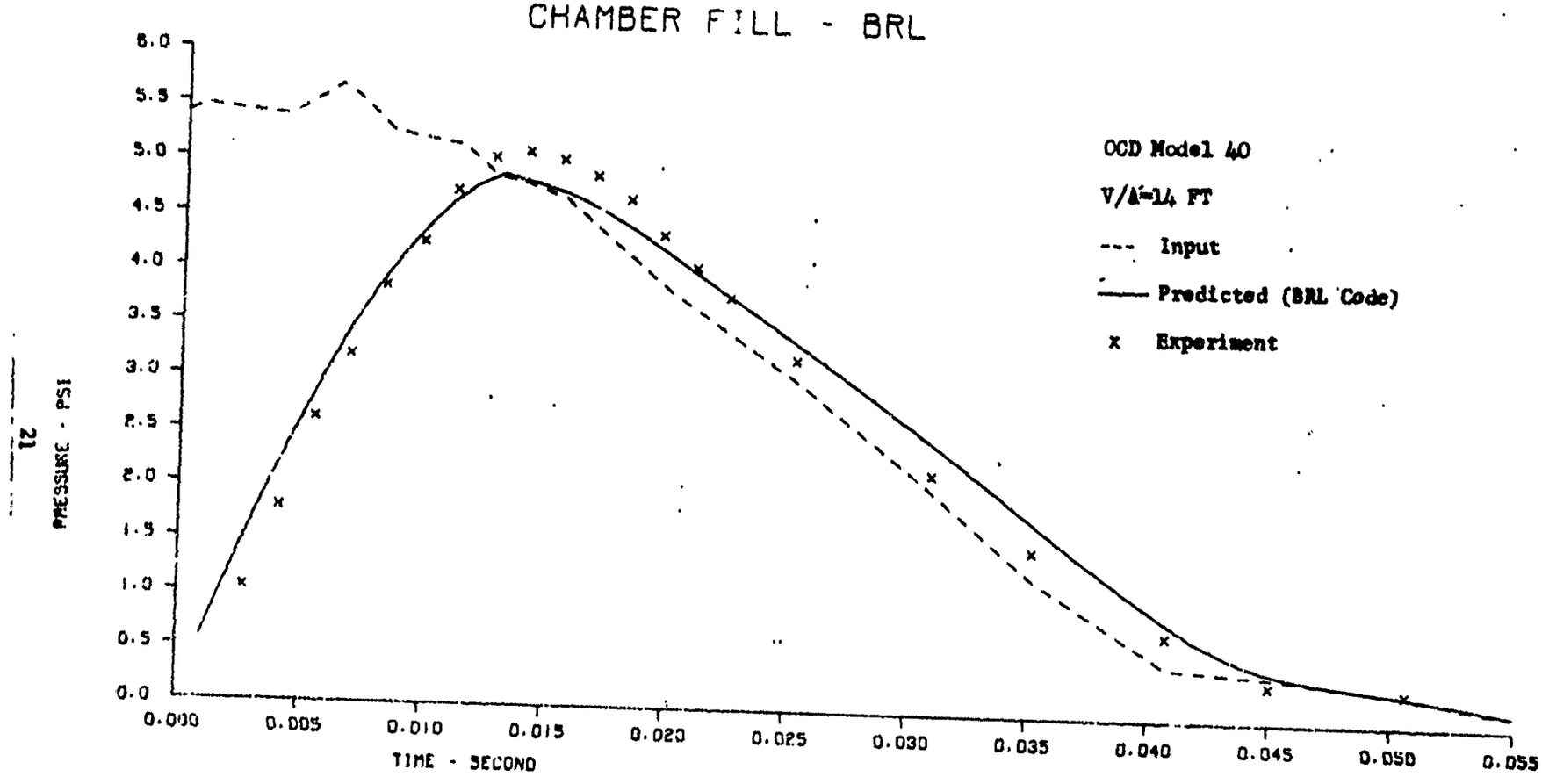


Figure 7. Plot Routine for Chamber Fill

but does not seem to better the predictions.

B. High Speed Photographs

Table A-I, Parts B and C (Appendix A) list the results of the experiments with small objects placed in the basement model. The motion as observed by the high speed camera is listed as a function of the type of stairway (open or closed), the position in the model, and the shock pressure, P_s, to which the model was exposed. Figure 8 illustrates one case of this motion. Other positions tested are shown in Appendix D. Post-shot still photographs are shown in Appendix E to show where the test objects finally ended up on the model basement floor. A general clockwise pattern of motion about the room was observed in the motion photographed. The details and magnitudes are summarized in Table A-I. These are pointed out in the Summary and Conclusion Section.

IV. SUMMARY AND CONCLUSIONS

The experiments reported made use of pressure transducers and high speed photography to measure the pressure-time profiles and flow effects at various locations inside a 1/12th scale model of a 100 person basement shelter.

The pressure transducers recorded three major wave shapes within the model during loading with exterior shock waves. (1) A low pressure dip was recorded at positions near the stairway and is attributed to a vortex sheet extending down from the stairwell. The greatest pressure dip, or lowest pressure, was measured near the widest stair opening which is at the foot of the stairs. (2) A generally smooth pressure filling curve was observed at positions near the center area of the floor. (3) Multiple pressure peaks were observed superimposed on the general filling curve when the transducer positions were near walls. These peaks were probably the result of internally reflected shock waves from the various interior surfaces.

SHOT 504

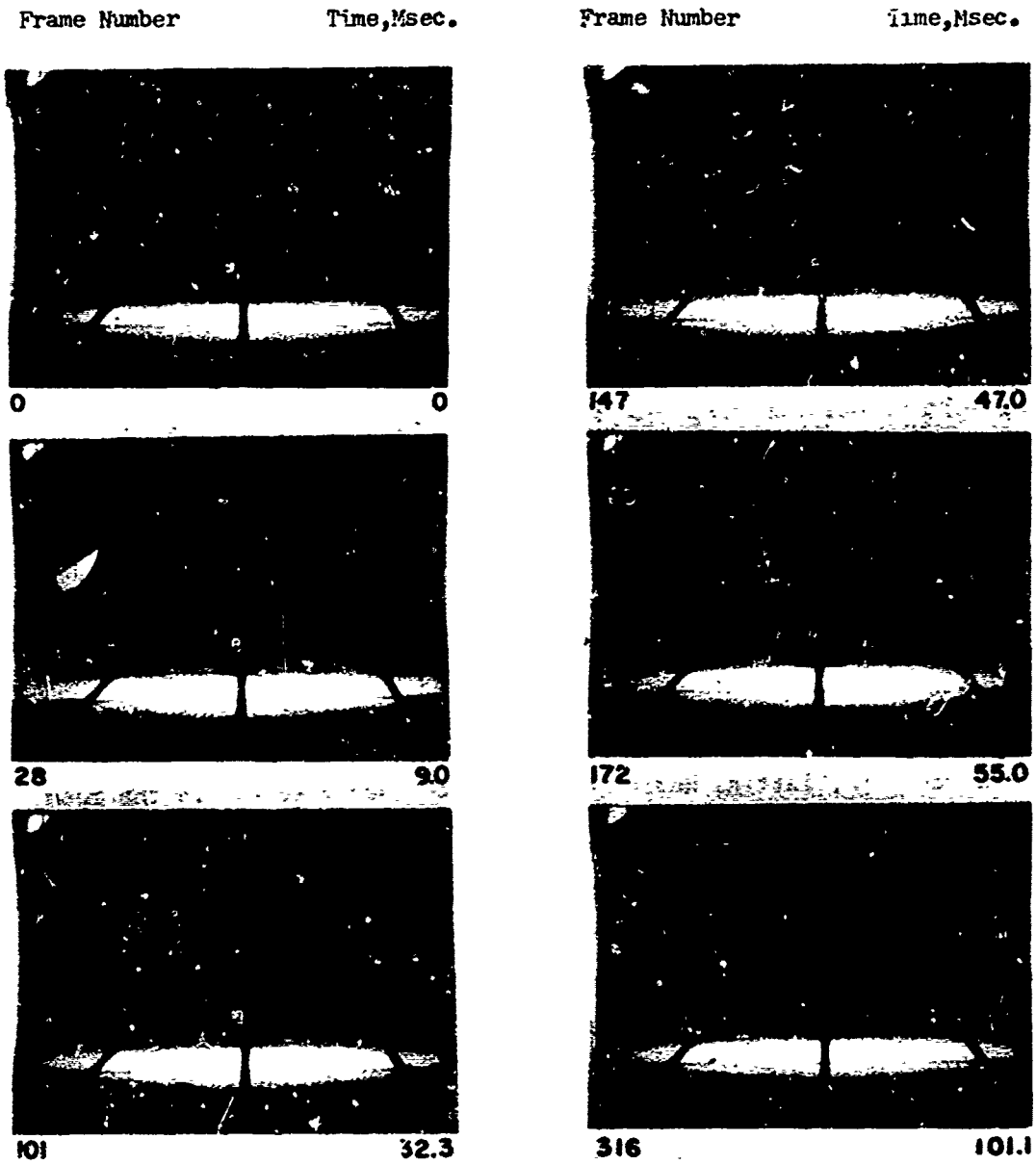


Figure 8. Open Stairway-Cylinders on Row 1 - 5.3psi

As the exterior loading shock wave was increased in over pressure from 5 - 20 psi, the low pressure vortex effect extended greater distances into the model, away from the stairway.

A comparison of the high speed pictures of the motion of the nylon cylinders for the case of the open stairway indicated the following things. (1) The general motion of all the cylinders indicated that the air flow spilled over the edge of the stairway and gave a clockwise rotation to the flow (for the model-shock wave orientation used). (2) The stronger flows existed near the bottom of the stairs since objects placed there showed the greatest motion. (3) Cross the floor components of velocity ranged from values of 4 - 14 ft/sec at Row 1 for initial motion (during time for the room to fill) to values of 1 - 2 ft/sec for long term velocities which occurred well after the room filled. (4) Motion appeared less at positions near the center area of the room.

The package containing all the objects moved much the same as the single cylinders did. The following observations were made. (1) The left front corner under the stairs seemed to give the most protection for the 5 and 10 psi loading. (2) All positions tested at the 20 psi loading showed motion of "pack". The component objects were blown out of the "pack" at velocities of 10 ft/sec to 82 ft/sec, for the lighter object "E". (3) Initial motion of the "pack" occurred within the room filling time.

A comparison of motions of the cylinders for the open and the closed stairway showed about the same kind of motion for each case. A somewhat smaller cross-room component of velocity was measured with the closed stairway except when the 20 psi shock wave was used. The incoming high speed flow was apparently expanded in area enough at the 20 psi loading to include the right end cylinder within the initial flow. The direction of motion changed from toward the right wall to a new direction, diagonally toward the left rear of the basement model. The long term motion of the cylinders seemed about the same for the open and closed stairways.

Work now in progress includes the addition of a side window to the present basement model to observe lengthwise motion along the room. A new model is being designed to simulate a 1000 shelteree size basement shelter. A much longer shock wave will be used to load the new model. This should help to predict the motion of the objects as a function of the exterior shock waveshape.

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APPENDIX A

TABLE A-I. SUMMARY OF SHOTS

Table A-I. Summary of Shots - Model 40

A. Pressure Measurements

Shot	P_s, psi	Position	P_{max}, psi	Waveshape	Location of Transducers	Remarks
482	5.0	1	5.3	Large pressure peaks	Floor Probe	Direction of shock wave travel is down the stairs. Open stairway. Pressure probes at all positions except Pos. 1.
		2	4.9	Small effect of vortex		
		3	4.9	Slight pressure peaks		
		4	4.8	Almost smooth fill		
		5	5.0	Medium pressure peaks		
		6	4.7	Pressure dip to zero		
		7	4.6	Similar to Pos. 3		
		8	5.3	Similar to Pos. 3		
		9	-	-		
		10	5.1	Large negative pressure dip		P_1 = 14.81 psi
		11	4.8	Similar to Pos. 8		
		12	4.9	Similar to Pos. 8		T_1 = 21.80°C
		13	5.1	Medium pressure peaks		
491	5.2	1	5.9	Large pressure peaks	Floor	Pressure transducers are all flush in the floor.
		2	5.3	No effect from vortex		
		3	5.2	Slight pressure peaks		
		4	5.2	Nearly smooth fill curve		
		5	5.2	Larger peak than Pos. 3		
		6	5.4	Pressure dip from vortex		P_1 = 14.87 psi
		7	4.5	Similar to Pos. 3		
		8	6.0	Small peaks - like Pos. 3		T_1 = 21.57°C
		9	5.6	Similar to Pos. 5		
		10	4.9	Similar to Pos. 6		
		11	5.3	Similar to Pos. 3		
		12	5.3	Small peaks - like Pos. 3		
		13	5.8	Similar to Pos. 5 and 9		

Table A-1. Summary of Shots - Model 40 (Continued)

A. Pressure Measurements (continued)

Shot	P_s, psi	Position	P_{max}, psi	Waveshape	Location of Transducers	Remarks
483	1 0	1	9.0	Large pressure peaks	Floor Probe	Pressure probes at all positions except Pos. 1.
		2	8.6	Medium pressure peaks		
		3	8.7	Slight pressure peaks		
		4	8.6	Nearly smooth		
		5	8.9	Medium pressure peaks		
		6	8.4	Negative pressure dip		P_1 = 14.79 psi
		7	8.3	Similar to Pos. 3		T_1 = 21.95°C
		8	8.6	Similar to Pos. 5		
		9	-	-		
		10	9.0	Large negative dip		
		11	8.3	Pressure dips to zero		
		12	7.8	Similar to Pos. 5		
		13	8.9	Similar to Pos. 5		
492	10.3	1	11.7	Large pressure peaks	Floor	Pressure transducers are all flush in the floor.
		2	10.3	Small pressure dip		
		3	10.3	Very small pressure dip		
		4	10.0	Smoothest of all positions		
		5	10.4	Medium pressure peaks		
		6	9.8	Pressure dips near zero		P_1 = 14.9 psi
		7	8.2	Similar to Pos. 3		T_1 = 21.7°C
		8	12.1	Similar to Pos. 5		
		9	10.9	Similar to Pos. 5		
		10	10.0	Pressure dips below zero		
		11	9.7	Similar to Pos. 3		
		12	9.7	Similar to Pos. 5		
		13	11.1	Similar to Pos. 5		

Table A-1. Summary of Shots - Model 40 (Continued)

A. Pressure Measurements (continued)

Shot	P_s, psi	Position	P_{max}, psi	Waveshape	Location of Transducers	Remarks
493	20.5	1	20.6	Large pressure peaks	Floor	Pressure transducers are all flush in the floor.
		2	19.3	Small vortex dip		
		3	19.0	Similar to Pos. 2		
		4	19.3	Small peaks		
		5	18.3	Medium peaks		
		6	19.8	Vortex dip below zero		P_1 = 14.91 psi
		7	-	-		T_1 = 22.0°C
		8	19.7	Similar to Pos. 4		
		9	18.9	Similar to Pos. 5		
		10	18.6	Vortex dip larger than Pos. 6		
		11	20.5	Similar to Pos. 10		
		12	18.2	Similar to Pos. 4		
		13	19.5	Similar to Pos. 5		
494	20.6	1-A	19.3	Large pressure peaks	Floor	Transducer flush in floor.
						P_1 = 14.87 psi
						T_1 = 22.92°C

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open

Shot	P_s, psi	Position of Objects	Motion of Objects	Remarks
504 505	5.3 5.2	Row 1	Cylinder "H" tips, moves at 4 ft/sec to right at 4.2 ms and away from steps - rolls back from right wall after rotation at average cross velocity of 2 ft/sec. Slight motion of cylinders "A" and "B" back toward stairs.	P_1 = 14.8 psi T_1 = 22.7°C Rows refer to Fig. 3. Time is measured from shock arrival at the top of stairs.
506	10.1	Row 1	"A" slid twd steps. "B" bottom moved left and side - rolled away from steps. "H" moved after 2.2 ms at 7.5 ft/sec - tilted twd R. wall - spun off - airborne w/rotation about long axis - hit middle of room, moved left 10.5 ft/sec to wall and return. In motion after 296 ms.	P_1 = 14.85 psi T_1 = 22.62°C All velocities are components in directions noted.
507	20.3	Row 1	"A" and "B" airborne - "A" moved twd steps. "B" moved away from steps. "H" apparently hit ceiling, then the floor and collided with "B". "A" began to move at 1.9 ms at 13.9 ft/sec. average 2.9 ft/sec to ceiling and return. In motion at 653 ms.	P_1 = 14.82 psi T_1 = 22.17°C

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open (continued)

Shot	P_s, psi	Position of Objects	Motion of Objects	Remarks
508	5.3	Row 2	"A" and "B" slid slightly to right of steps - did not fall. "H" tips right, falls twd wall. Motion begins at 6.1 ms, 2 ft/sec to right. Motion at 2.5 ms.	P_1 = 14.84 psi T_1 = 22.36°C
509	5.3	Row 3	Almost no motion for all cylinders.	P_1 = 14.79 psi T_1 = 21.82°C
510	10.3	Row 3	"A" moved toward stairs and to left. "B" and "H" moved to right - did not tip. Motion stopped after 155 ms.	P_1 = 14.79 psi T_1 = 21.92°C
511	10.2	Row 4	Movement to left at 5.6 ms-all lift off floor - slide toward stairs. "H" moved left at 2.1 ft/sec. Motion stopped at 213 ms.	P_1 = 14.8 psi T_1 = 21.85°C All components in directions noted.
512	10.1	Row 5	All were airborne in direction away from right rear corner. "H" moved at 14.8 ms. Average velocity of "B" to return to floor, 1.8 ft/sec. Motion at 298 ms.	P_1 = 14.8 psi T_1 = 21.82°C
513	5.4	Left corner under stairs	No noticable motion of pack.	P_1 = 14.69 psi T_1 = 21.34°C All objects were used (See Table I).

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open (continued)

Shot	P_s, psi	Position of Objects	Motion of Objects	Remarks
514	10.3	Left corner under stairs.	Pack was slightly separated during shot, after 26.3 ms.	P_1 = 14.83 psi T_1 = 20.60°C
515	20.5	Left corner under stairs.	Pack was blown apart. Object "G" is thrown up and out of Pack. Motion began 9.8 ms. 106 ms for "G" to hit ceiling.	P_1 = 14.83 psi T_1 = 20.68°C
517	10.5	Left corner under stairs - tied.	Little motion.	P_1 = 14.88 psi T_1 = 22.47°C
518	20.5	Left corner under stairs - tied.	Scattered across room.	P_1 = 14.94 psi T_1 = 21.57°C
519	20.5	Left front wall under stairs.	Pack moved right in 2.2 ms. "G" hit right wall and returned, 36.7 ft/sec average. Motion continued after 576 ms.	P_1 = 14.95 psi T_1 = 22.45°C

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open (continued)

Shot	P_s, psi	Position of Objects	Motion of Objects	Remarks
520	21.0	Center of end wall away from stairs.	Objects scattered up left side of floor. Pack flew upwards, to left, and apart. "A" moved at 2.6 ms. "I" hit ceiling at 13.4 ft/sec. "F" moves left at 25.6 ft/sec. "G" circulates right at 5.9 ft/sec. Movement after 491 ms.	P_1 = 14.95 psi T_1 = 22.03°C All velocities are components in directions noted.
521	5.4	Row 1 - Cylinders tied.	To right and away from stairs.	P_1 = 14.89 psi T_1 = 22.0°C
522	5.3	Right rear corner, away from stairs.	Slight movement.	P_1 = 14.88 psi T_1 = 21.95°C
523	10.5	Right rear corner, away from stairs.	Pack scattered across rear of floor. Pack moved at 7 ms. "E" moved left at 12.6 ft/sec. "I's" still in air at 292 ms.	P_1 = 14.88 psi T_1 = 21.99°C
524	5.2	Left rear corner, away from stairs.	Almost no movement.	P_1 = 14.89 psi T_1 = 22.55°C
525	10.3	Left rear corner, away from stairs.	Pack moved slightly out from the corner.	P_1 = 14.91 psi T_1 = 22.19°C

Table A-1. Summary of Shots - Model 40 (Continued)

B. Photographic Measurements - Stairway Open (continued)

Shot	P_s, psi	Position of Objects	Motion of Objects	Remarks
526	20.7	Left rear corner, away from stairs.	Pack shifted left. "I" hit ceiling at 10.7 ft/sec average velocity. "E" moved right at average of 82 ft/sec. Pack bursts up at 491 ms. towards stairs.	Time used from Shot 525.
529	5.3	Streamers on Rows 1, 3 and 5.	Row 1 moved in 1.2 ms. Row 3 moved in 1.6 ms. Row 5 moved in 2.0 ms. Full flow about 17.2 ms. Reversed flow at 18.8 ms. Outflow stops about 200 ms.	Mylar streamers P_1 = 14.88 psi T_1 = 21.85°C No objects for this shot.

Table A-1. Summary of Shots - Model 40 (Continued)

C. Photographic Measurements - Closed Stairway

Shot	P_s, psi	Position of Objects	Motion of Objects	Remarks
533	5.2	Row 1	Right cylinder moves from stairs, airborne towards right wall, hit and rolled back towards center at 1.8 ft/sec. Other cylinders did not move.	4.75" X 8" door into model basement. P_1 = 14.97 psi T_1 = 25.05°C Time zero is shock arrival at doorway.
534	10.2	Row 1	Right cylinder airborne to right rear, away from stairs, 3.8 ft/sec. Middle cylinder moved slightly right, 1.6 ft/sec. Left cylinder did not move.	P_1 = 14.92 psi T_1 = 23.37°C
535	10.2	Row 3	Right cylinder fell away from steps, rolled to center rear. The other two cylinders fell back toward stairway, 1-3 ft/sec.	P_1 = 14.92 psi T_1 = 23.41°C
536	10.2	Row 5	Right cylinder moved to rear and center, bounced back. The other cylinders move to left wall and back to wall at stairs, 1-3 ft/sec.	P_1 = 14.91 psi T_1 = 23.47°C

Table A-1. Summary of Shots - Model 40 (Continued)

C. Photographic Measurements - Closed Stairway (Continued)

Shot	P_s, psi	Position of Objects	Motion of Objects	Remarks
537	20.6	Row 1	Right cylinder airborne to left rear corner from stairs at 18.4 ft/sec. Center cylinder moves right 3-6 ft/sec, it is airborne. Left cylinder moves right airborne, 1 ft/sec.	P_1 = 14.84 psi T_1 = 21.26°C
538	21.0	Row 3	All cylinders became airborne. Right hand cylinder moved diagonally towards left rear at 8.7 ft/sec. to left. The other cylinders moved left and to front near stairway 2-3 ft/sec.	P_1 = 14.84 psi T_1 = 21.32°C All velocities are components in directions noted.
539	20.7	Row 5	Right hand cylinder moved to center rear 3-4 ft/sec and bounced off to left wall. Other cylinders moved to left and back to stairs 1.5 - 2.2 ft/sec.	P_1 = 14.81 psi T_1 = 21.39°C

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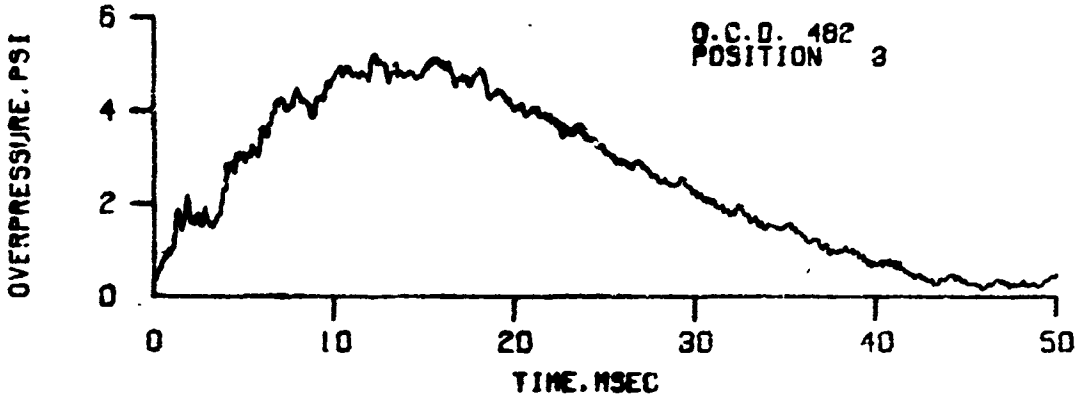
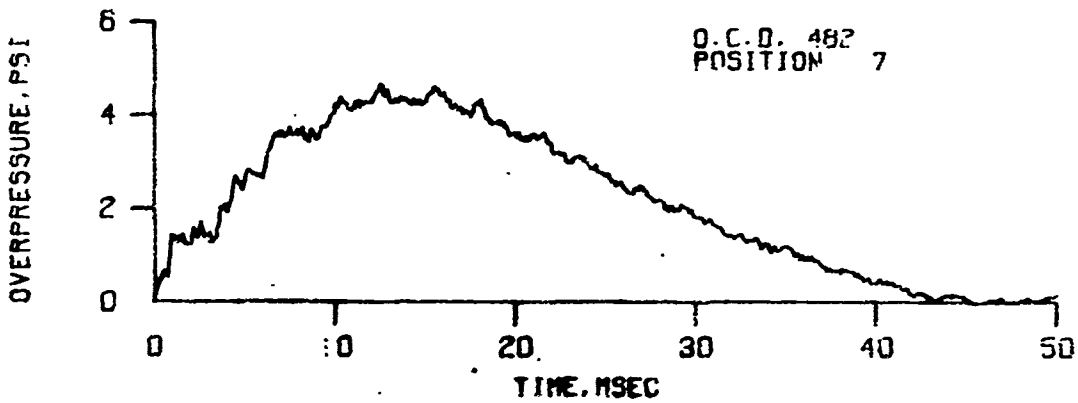
APPENDIX B

PRESSURE-TIME RECORDS - MODEL 40





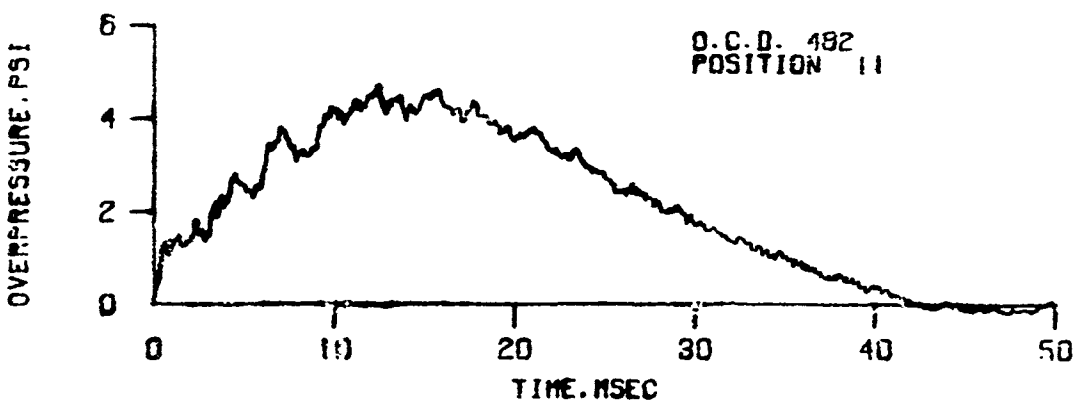
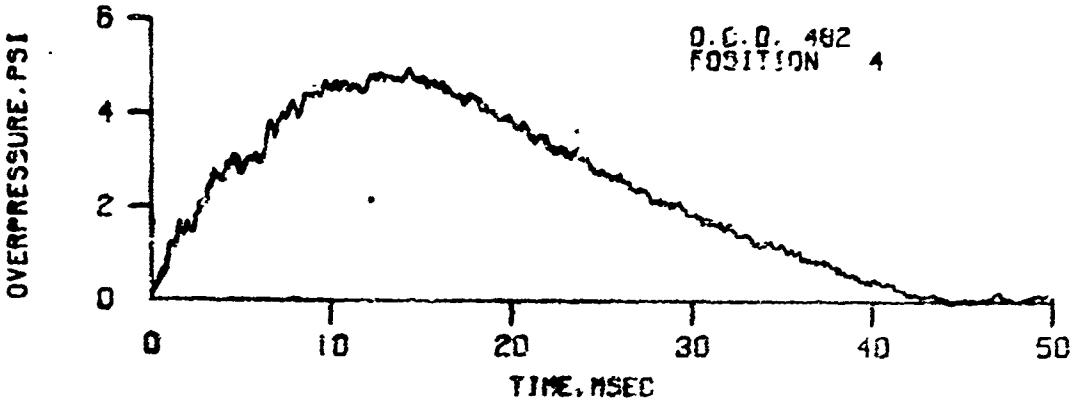
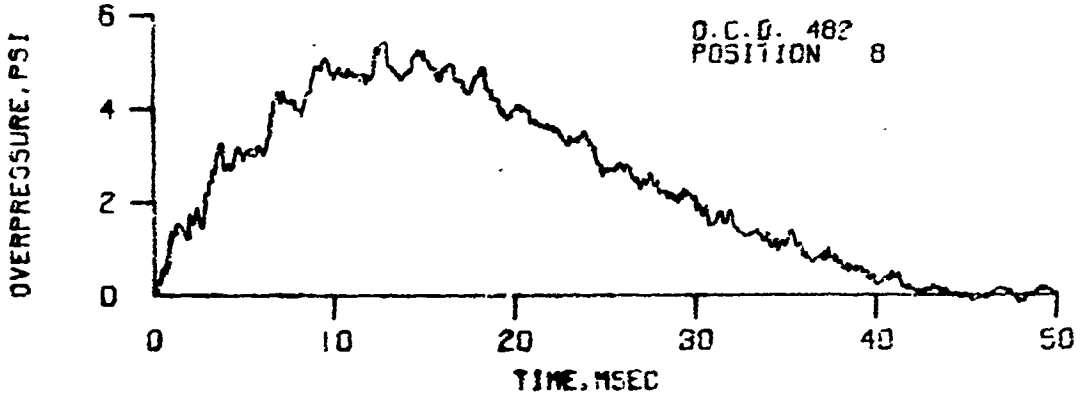
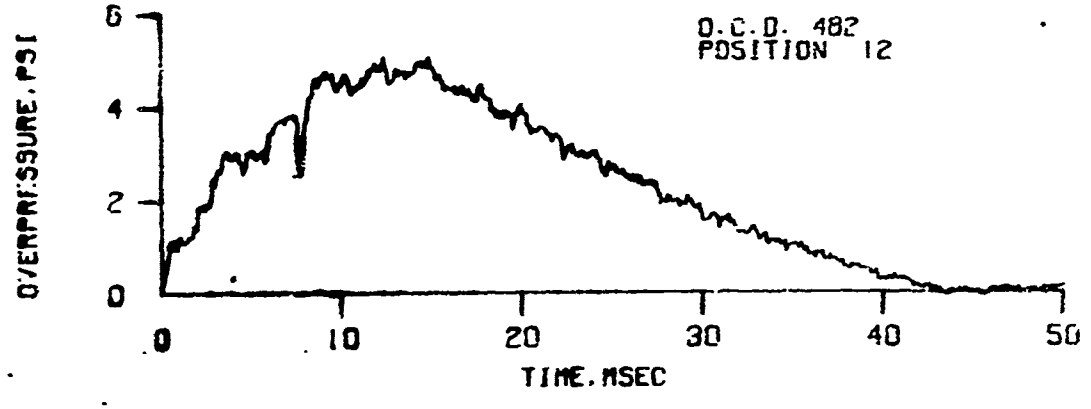


Figure B-1. Records from the Pressure Probes - P_s = 5psi







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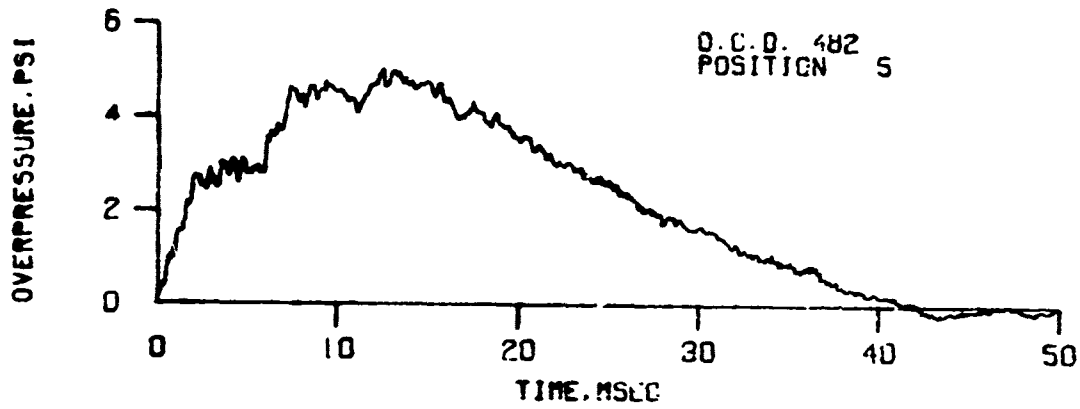
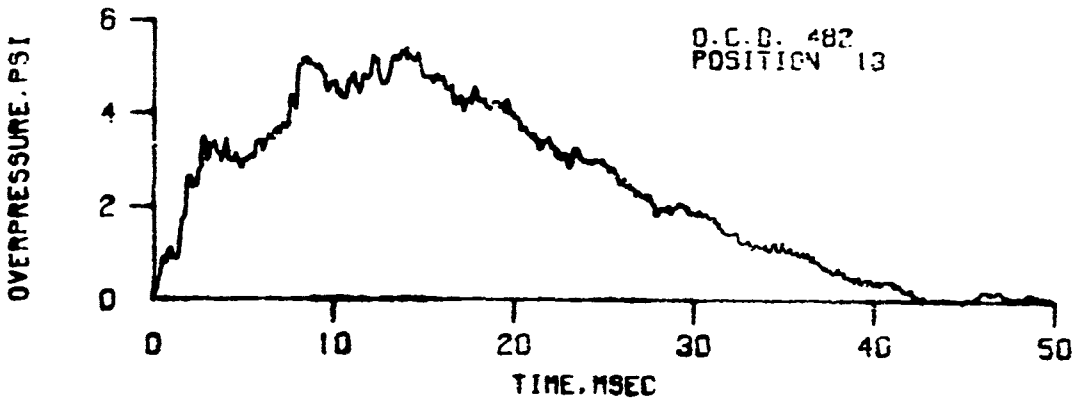


Position 9 Lost



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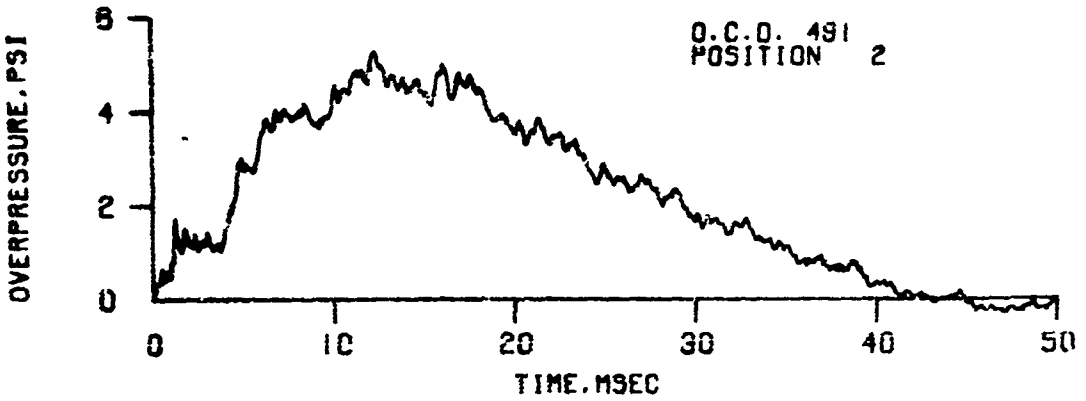
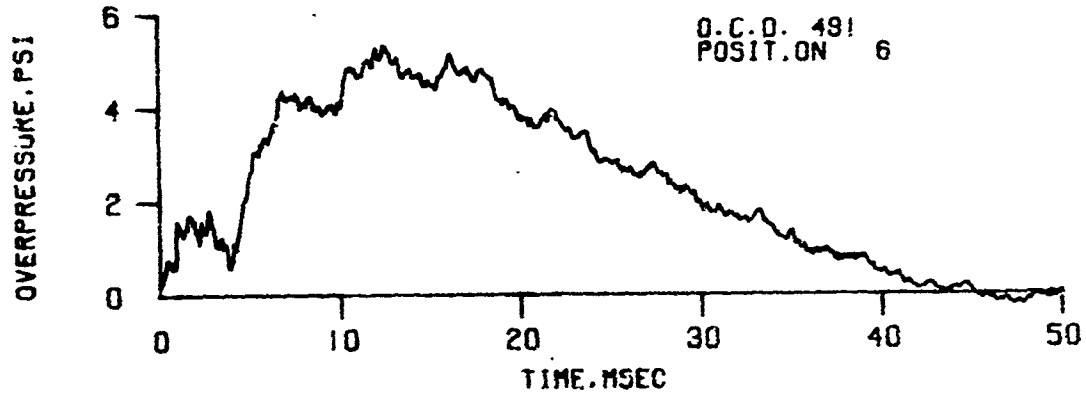




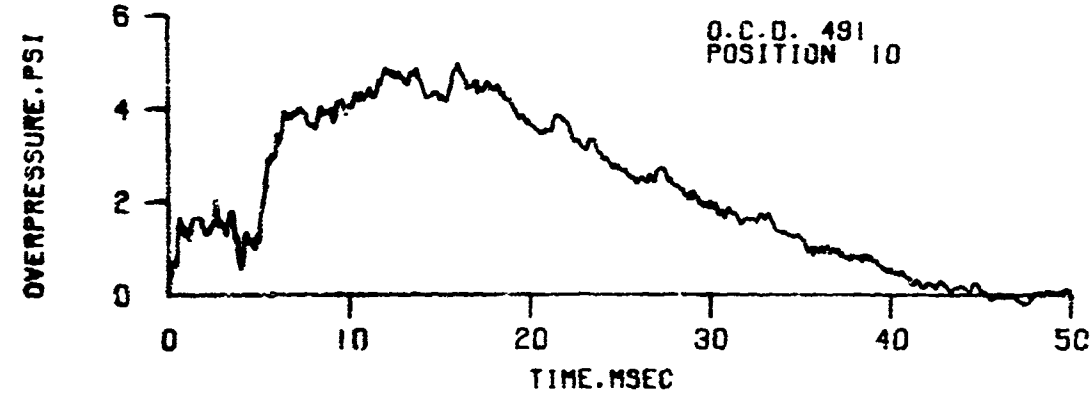
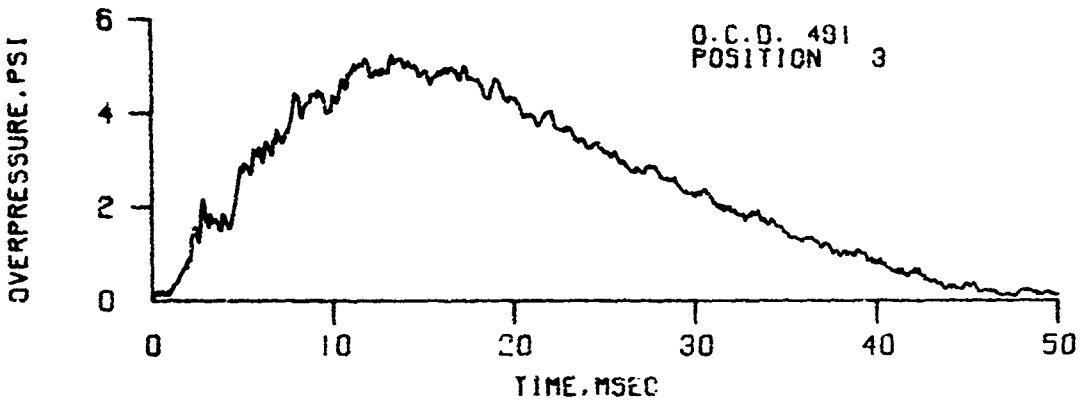
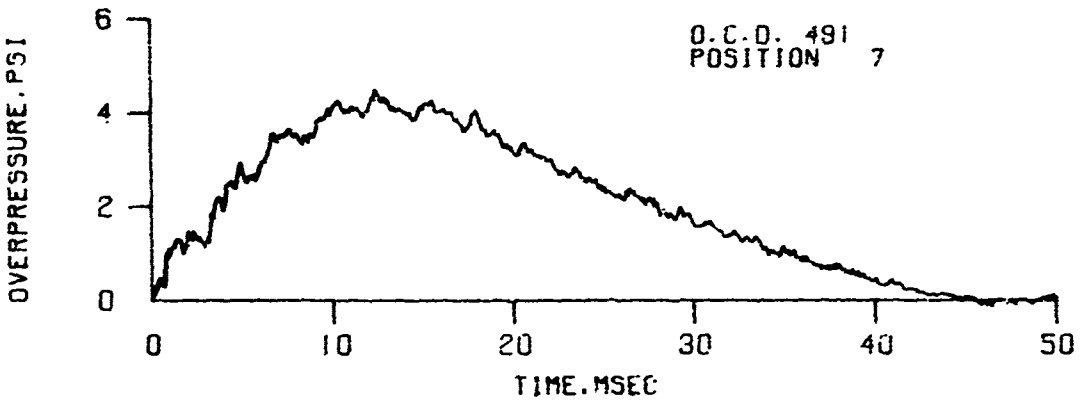
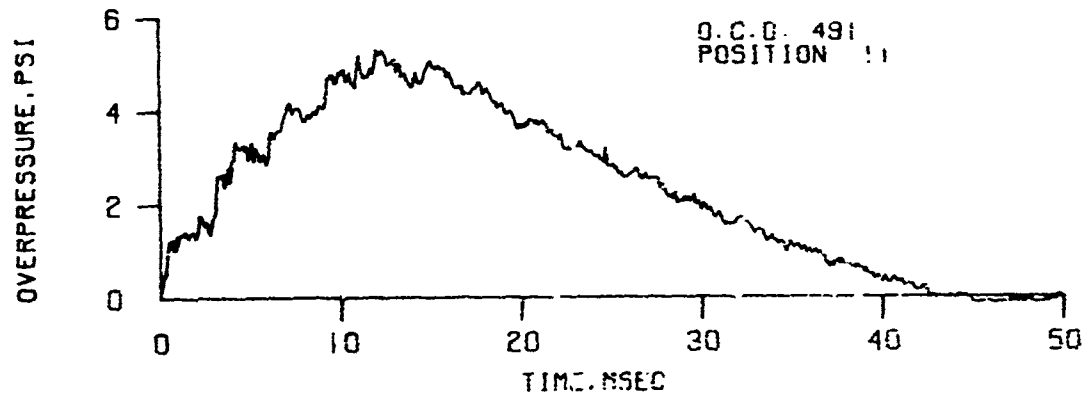


Figure B-2. Records from the Floor Transducers - P_s =5.2psi







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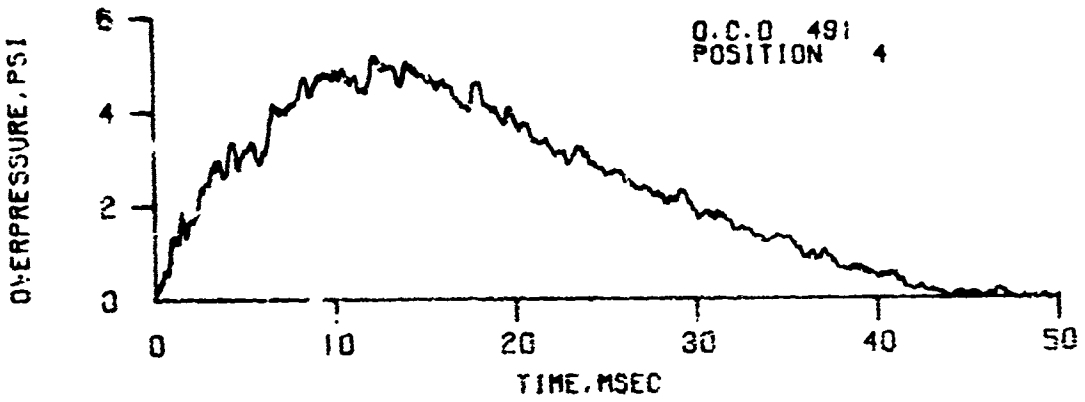

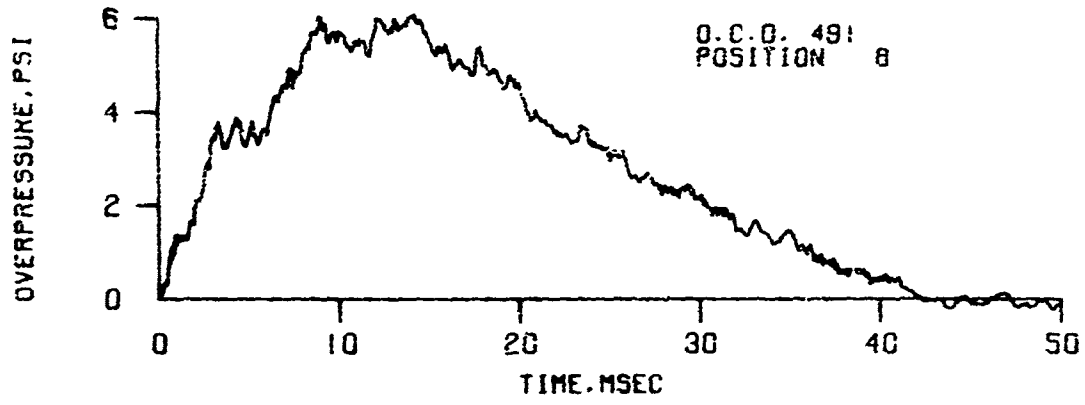

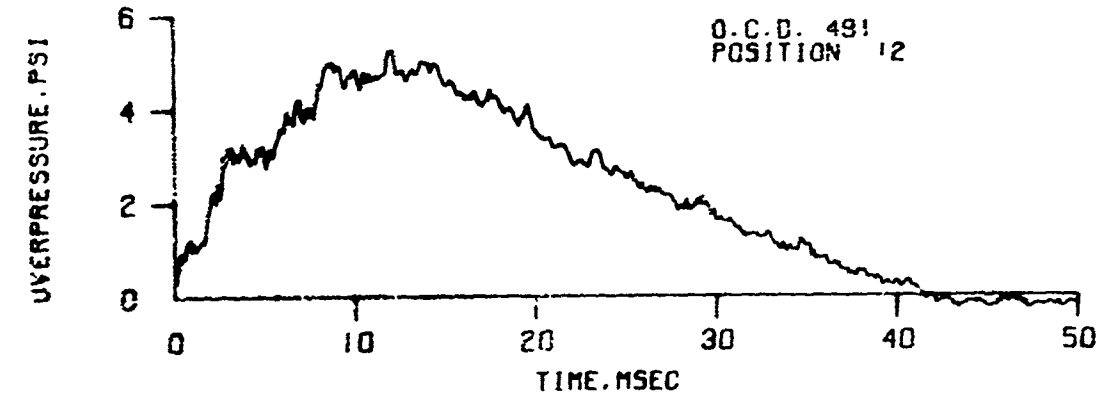

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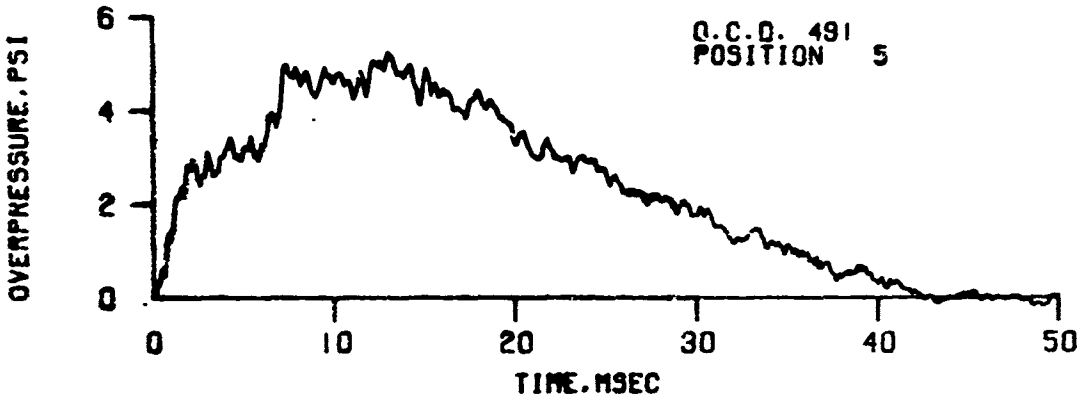

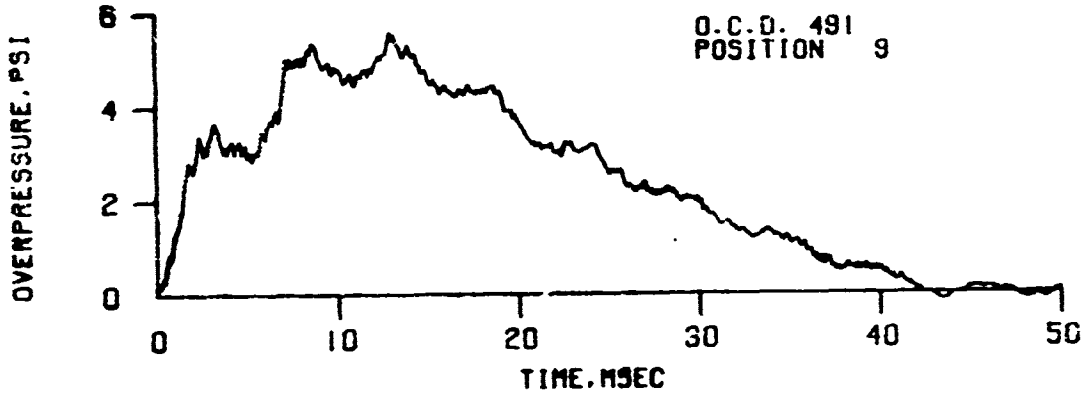

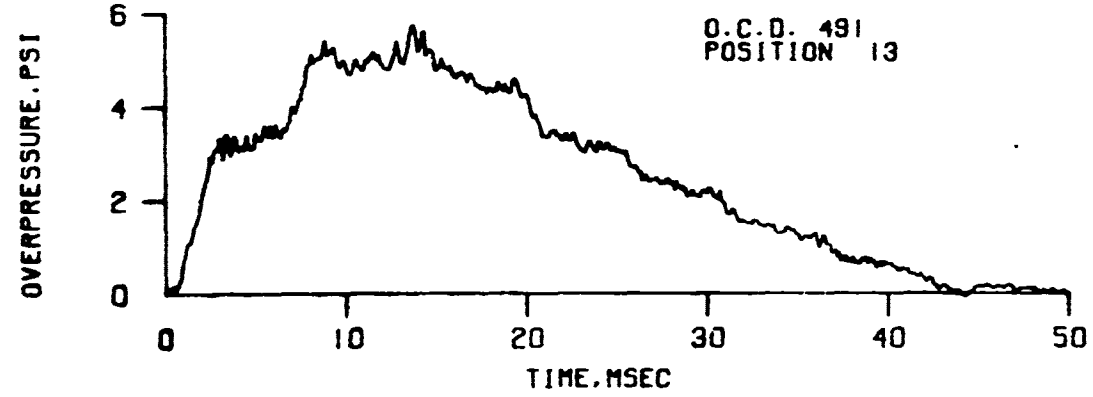

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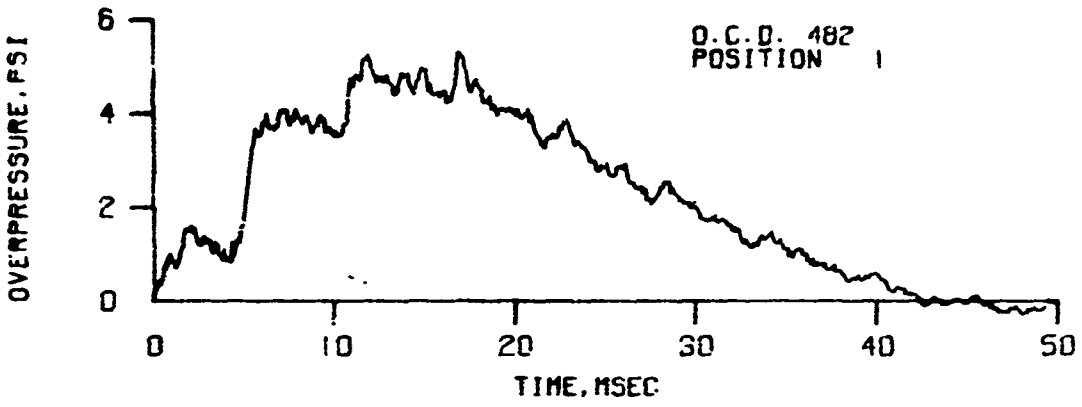


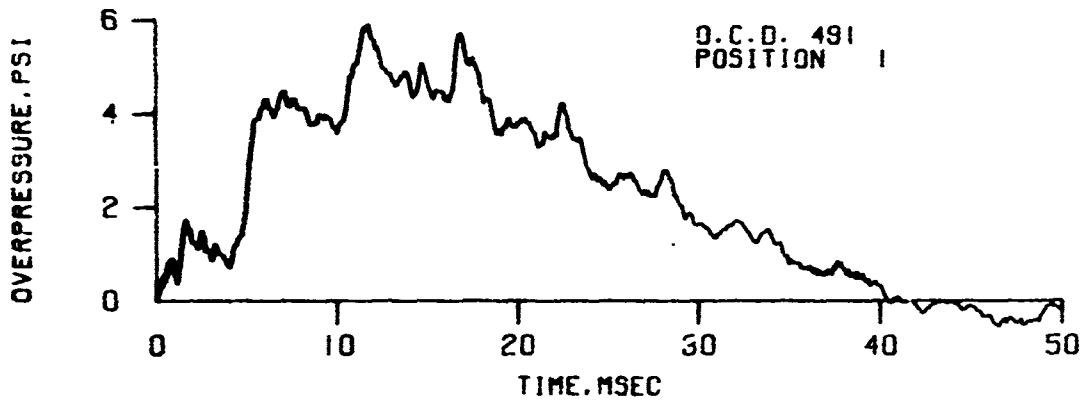


Figure B-3. Comparison of Position 1 - P_s = 5psi

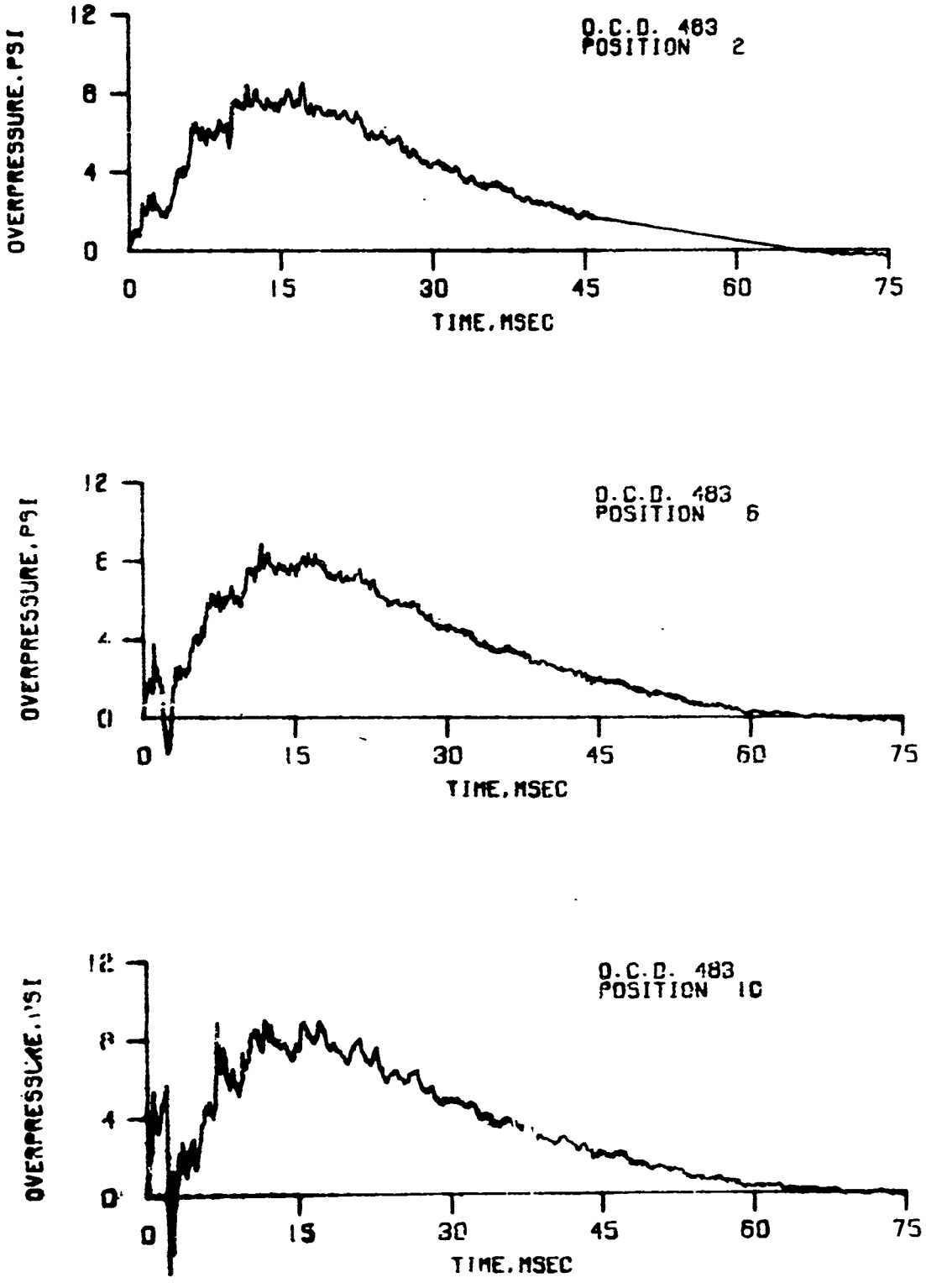
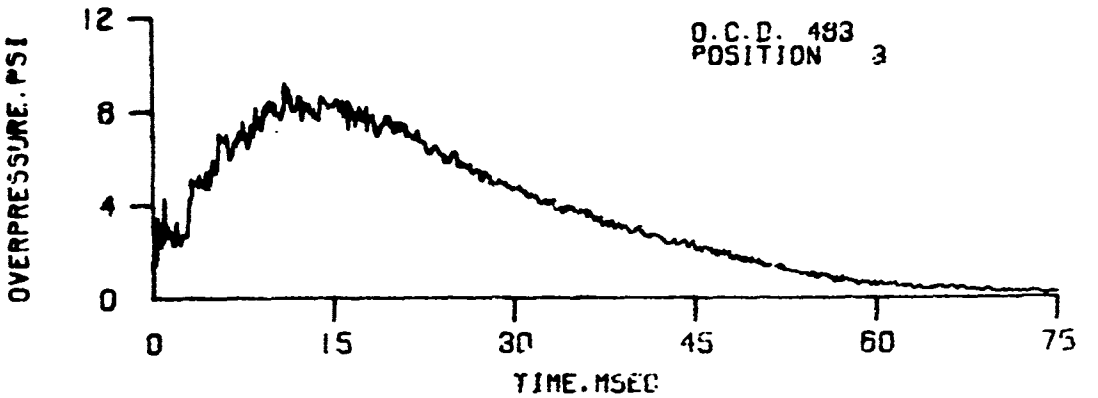
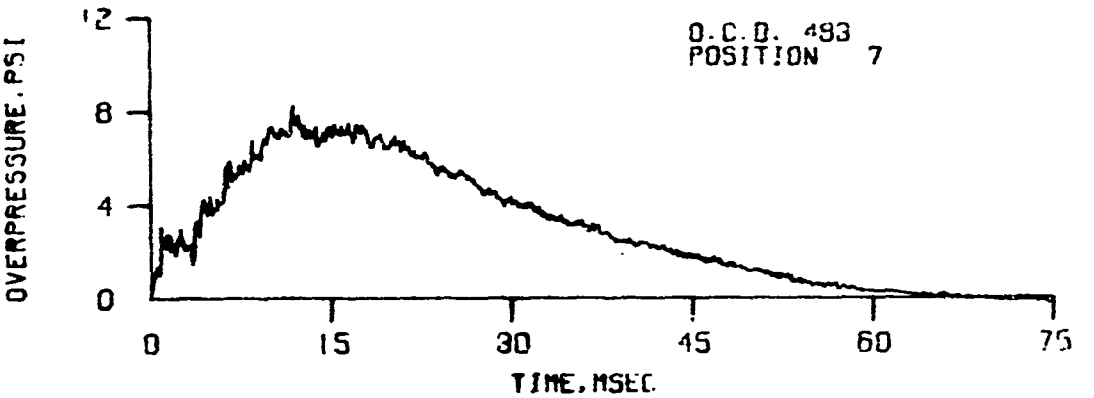
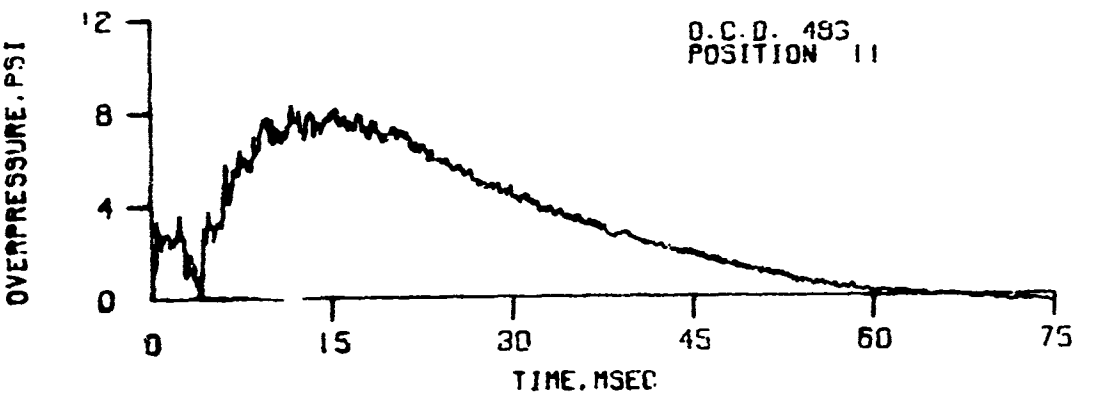


Figure B-4. Records from the Pressure Probes - P_s = 10psi







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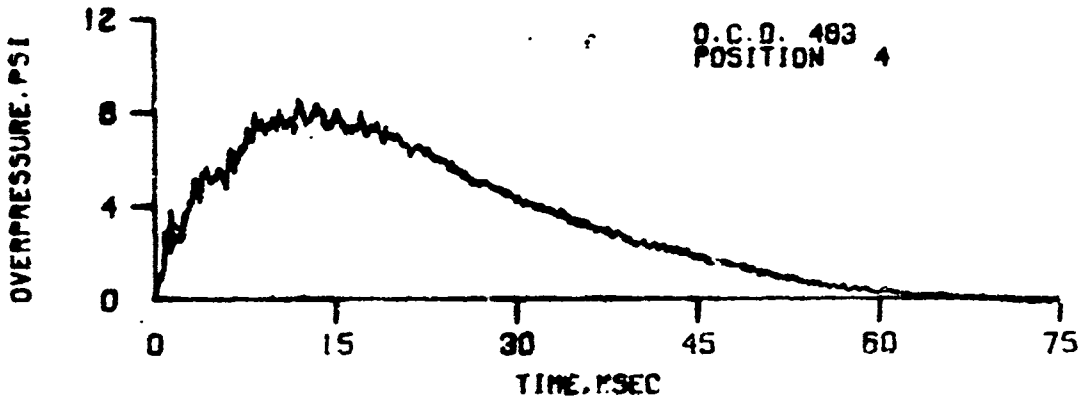

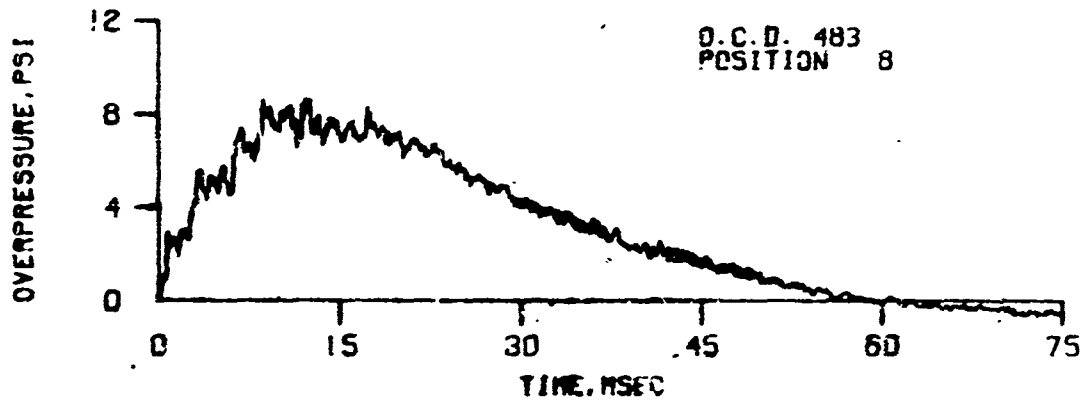

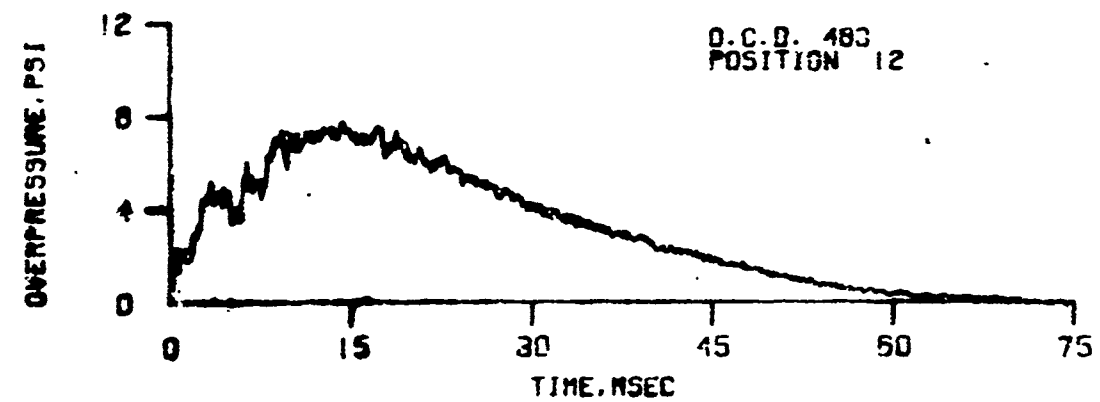

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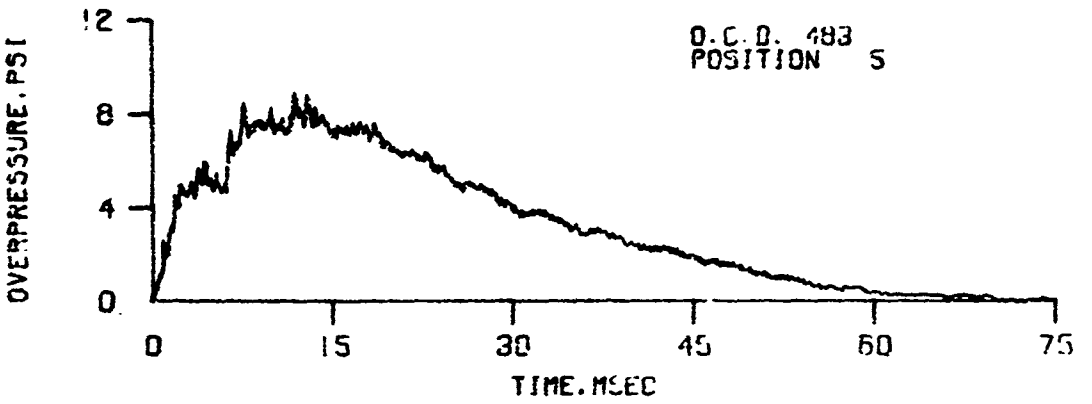

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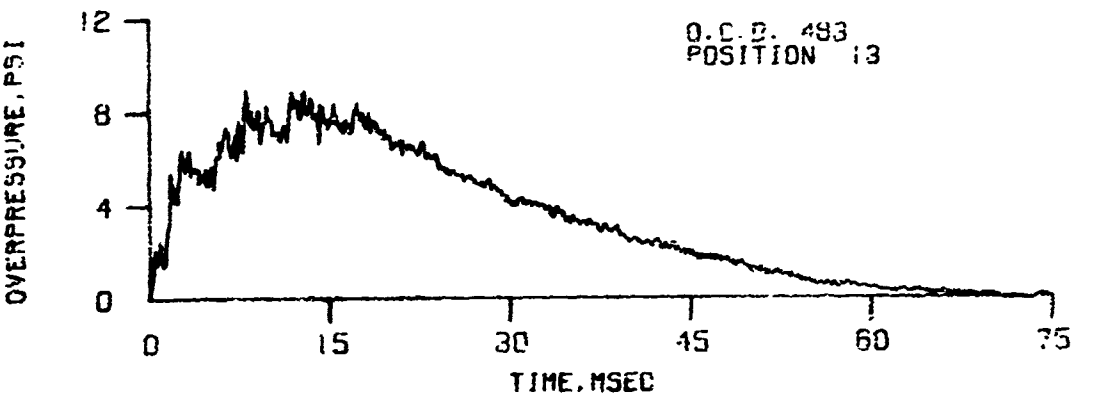

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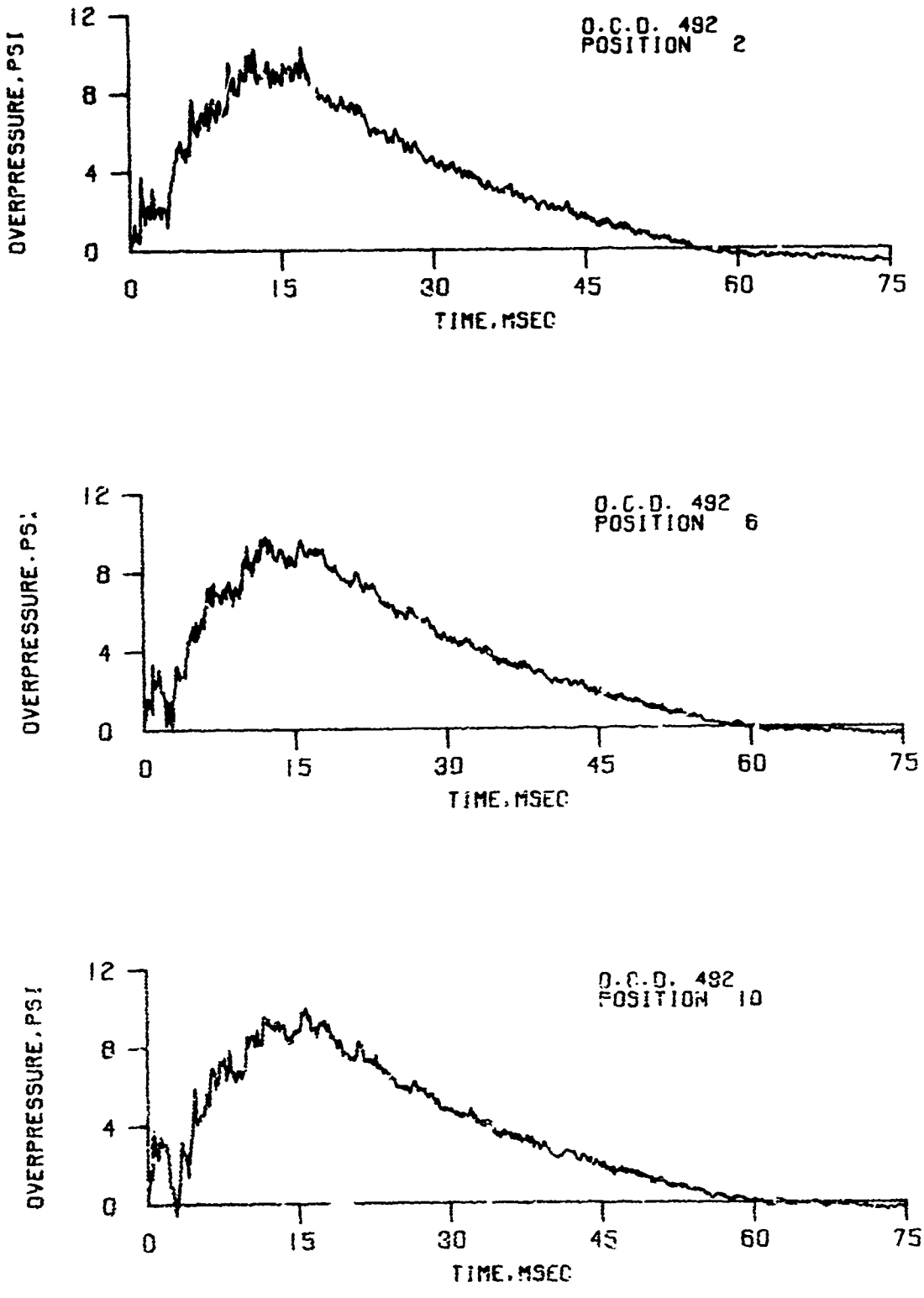
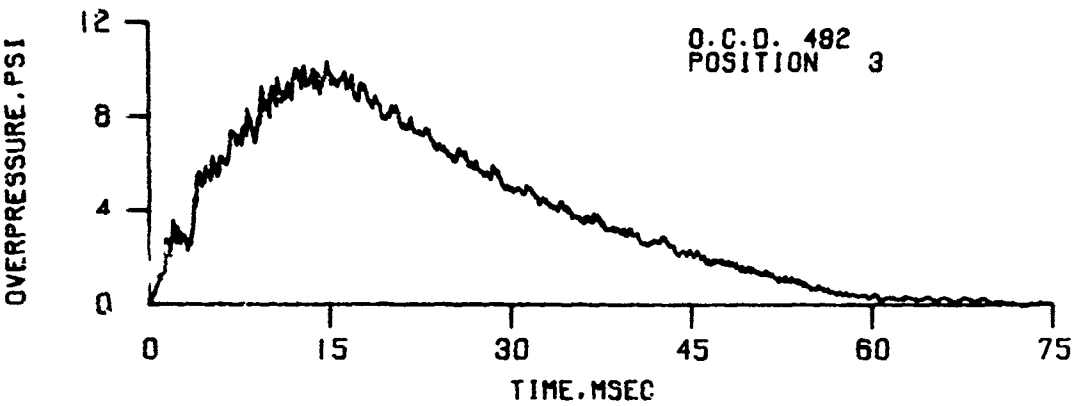
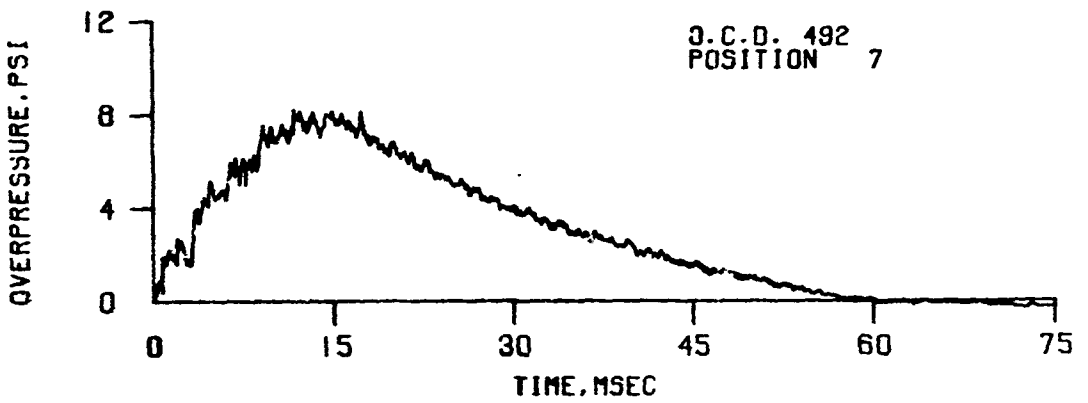
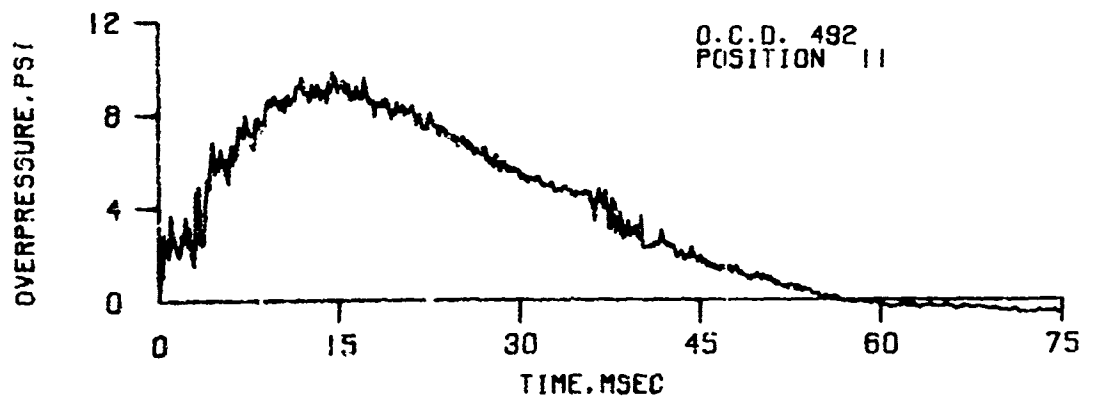


Figure B-5. Records from the Floor Transducers - P_s = 10.3psi







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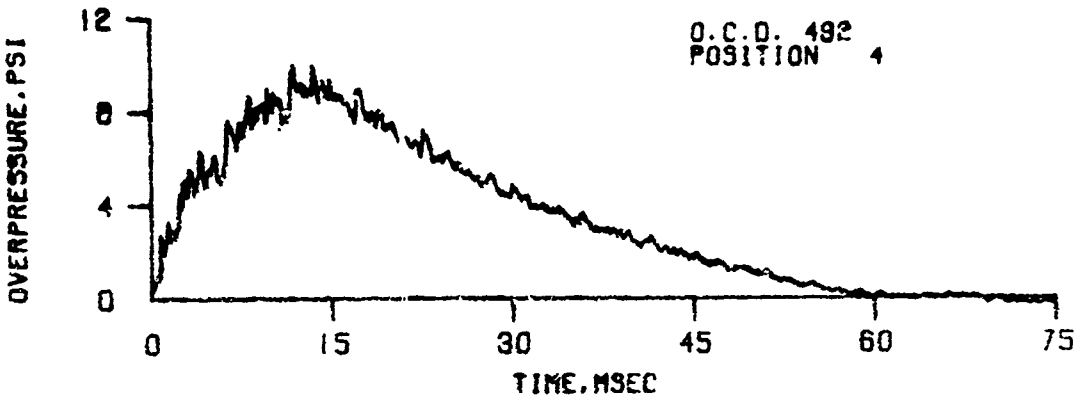

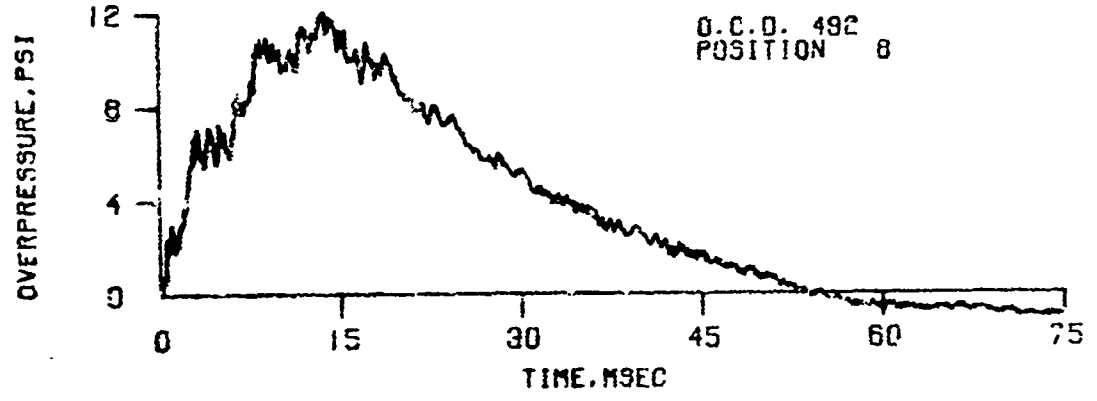

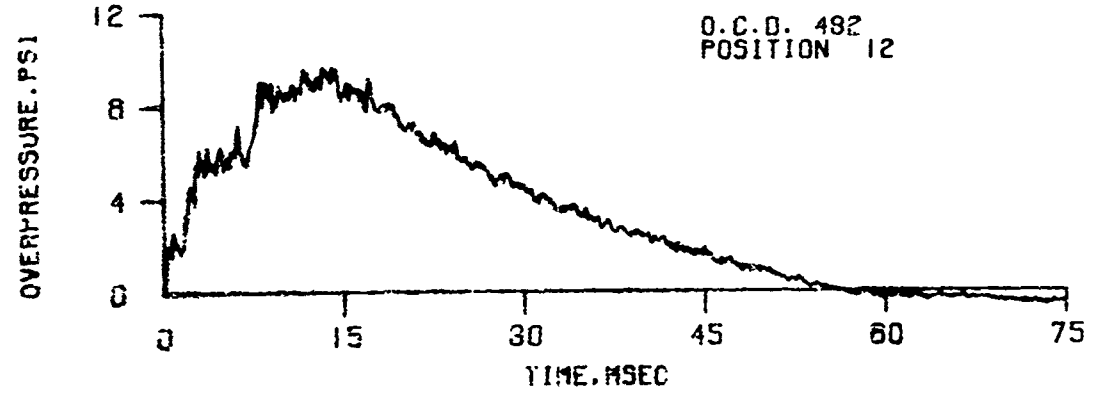

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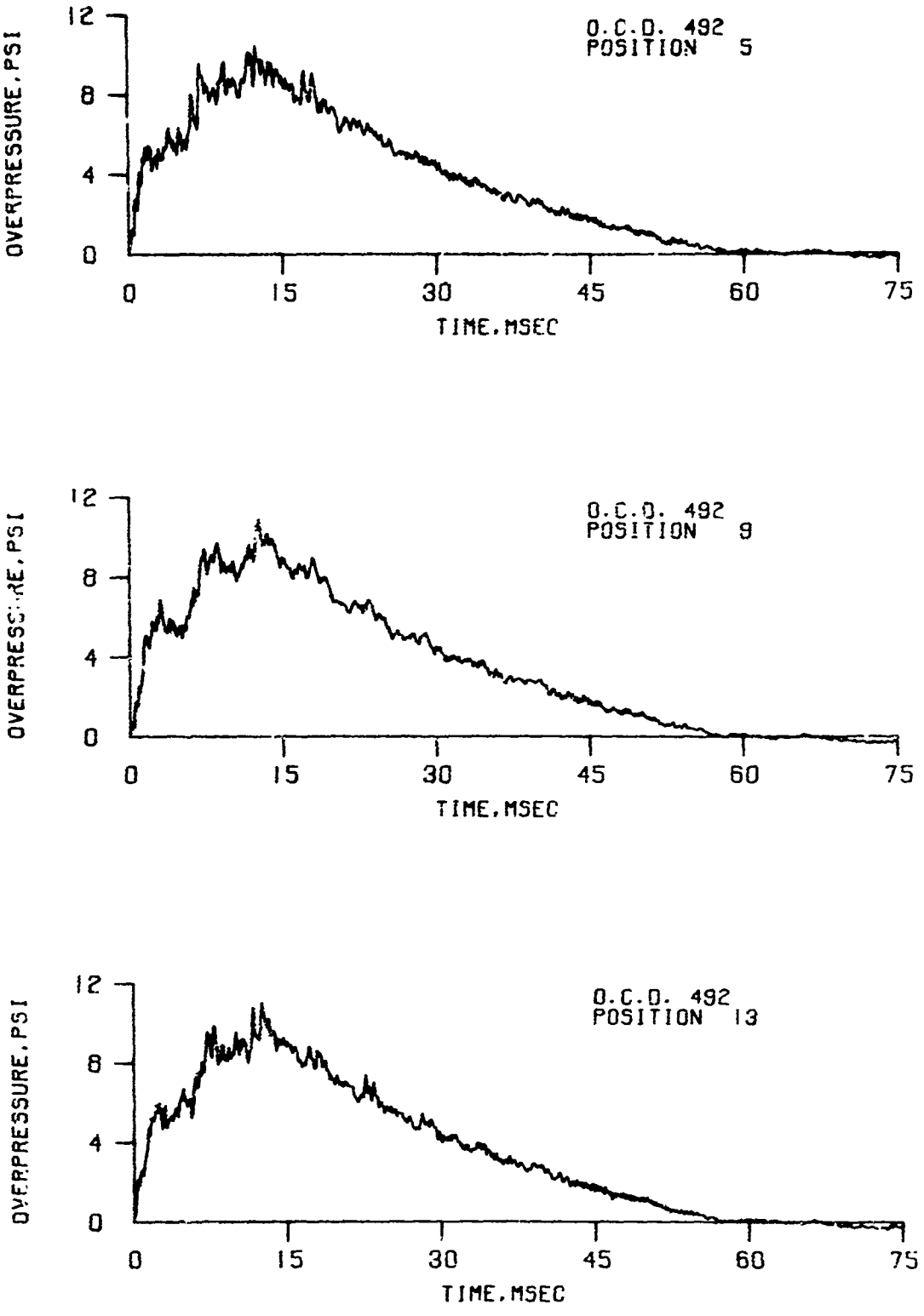

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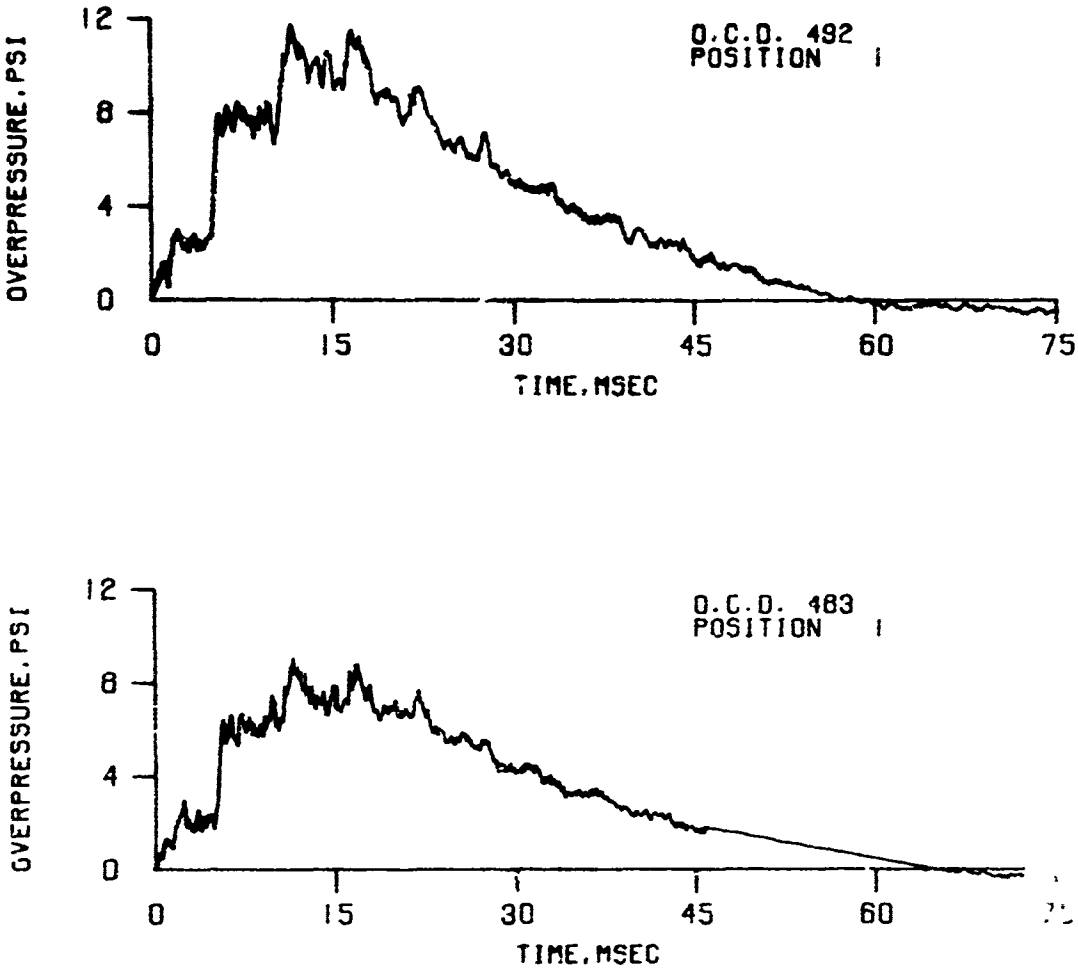
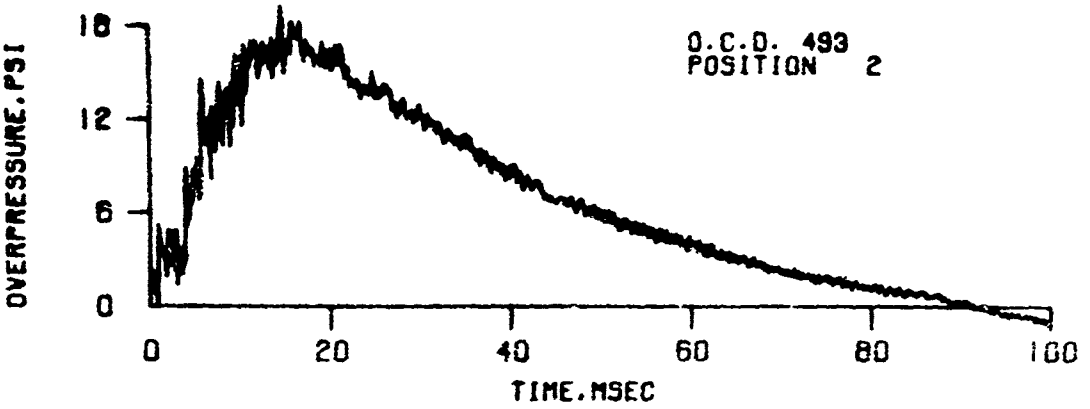
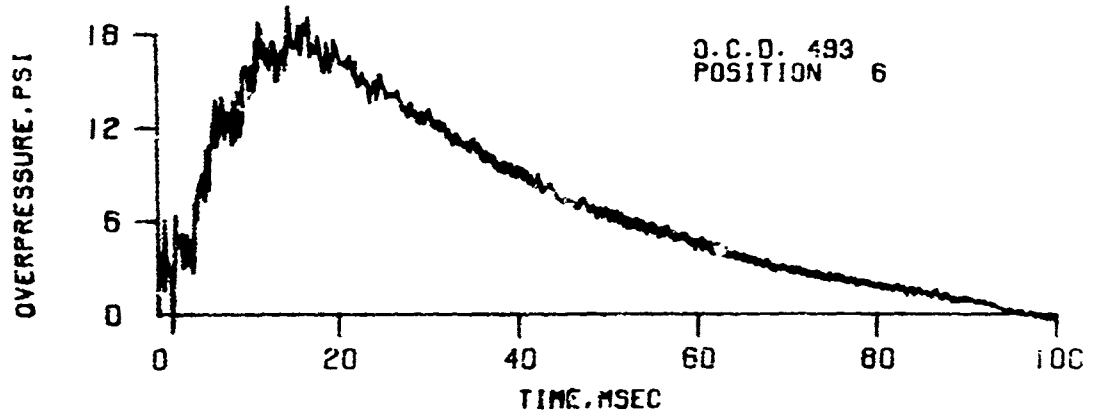


Figure B-6. Comparison of Position 1 - P_S = 10psi





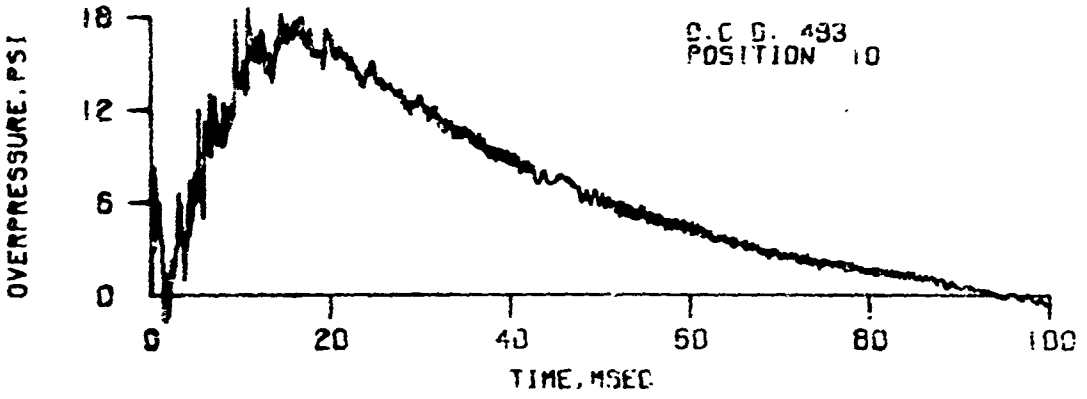
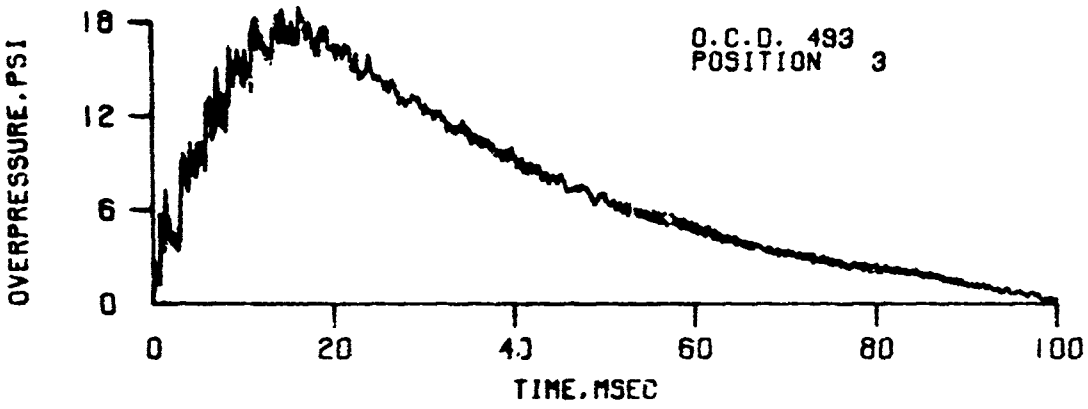


Figure B-7. Records from the Floor Transducers - P_s = 20psi



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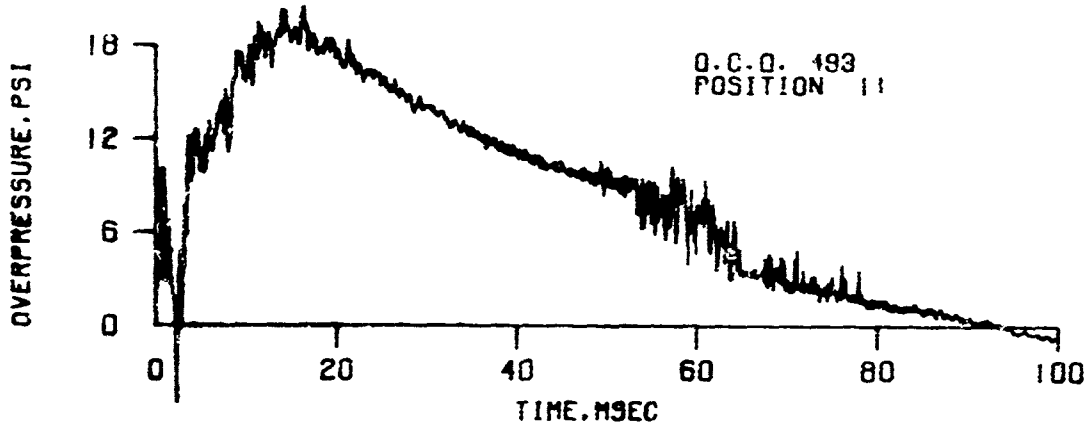

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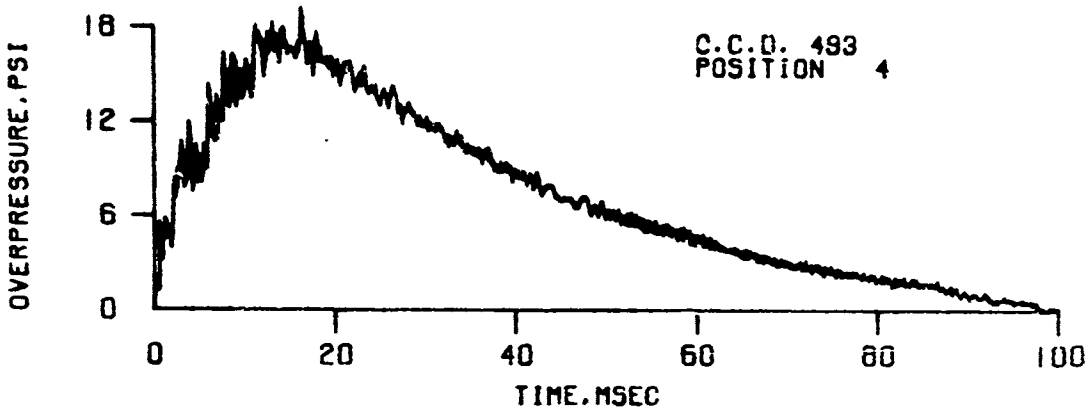
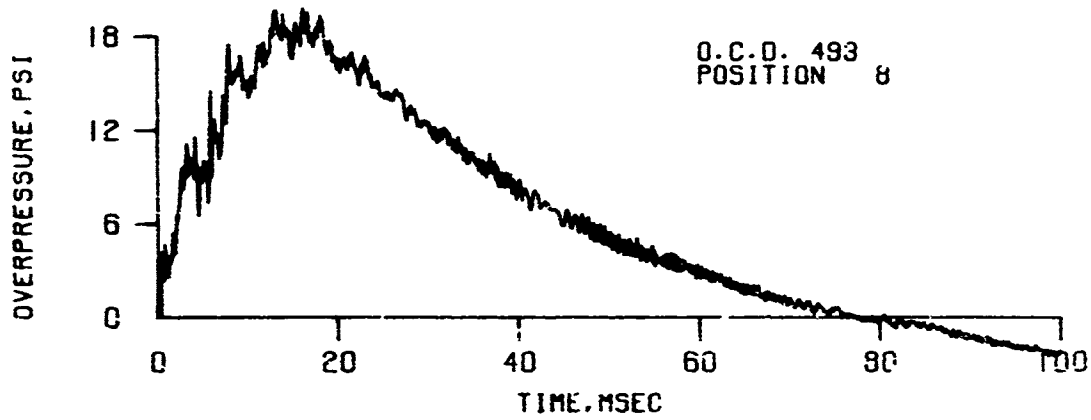




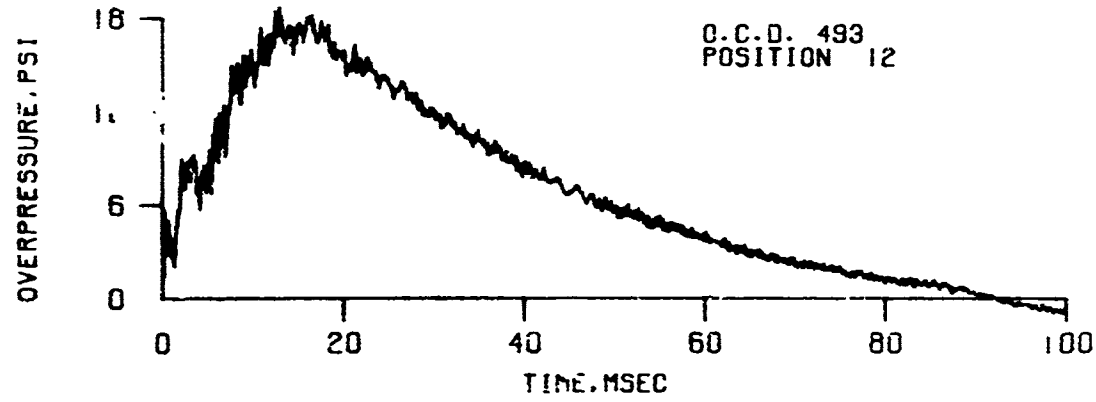


Figure 3-7. (Continued)

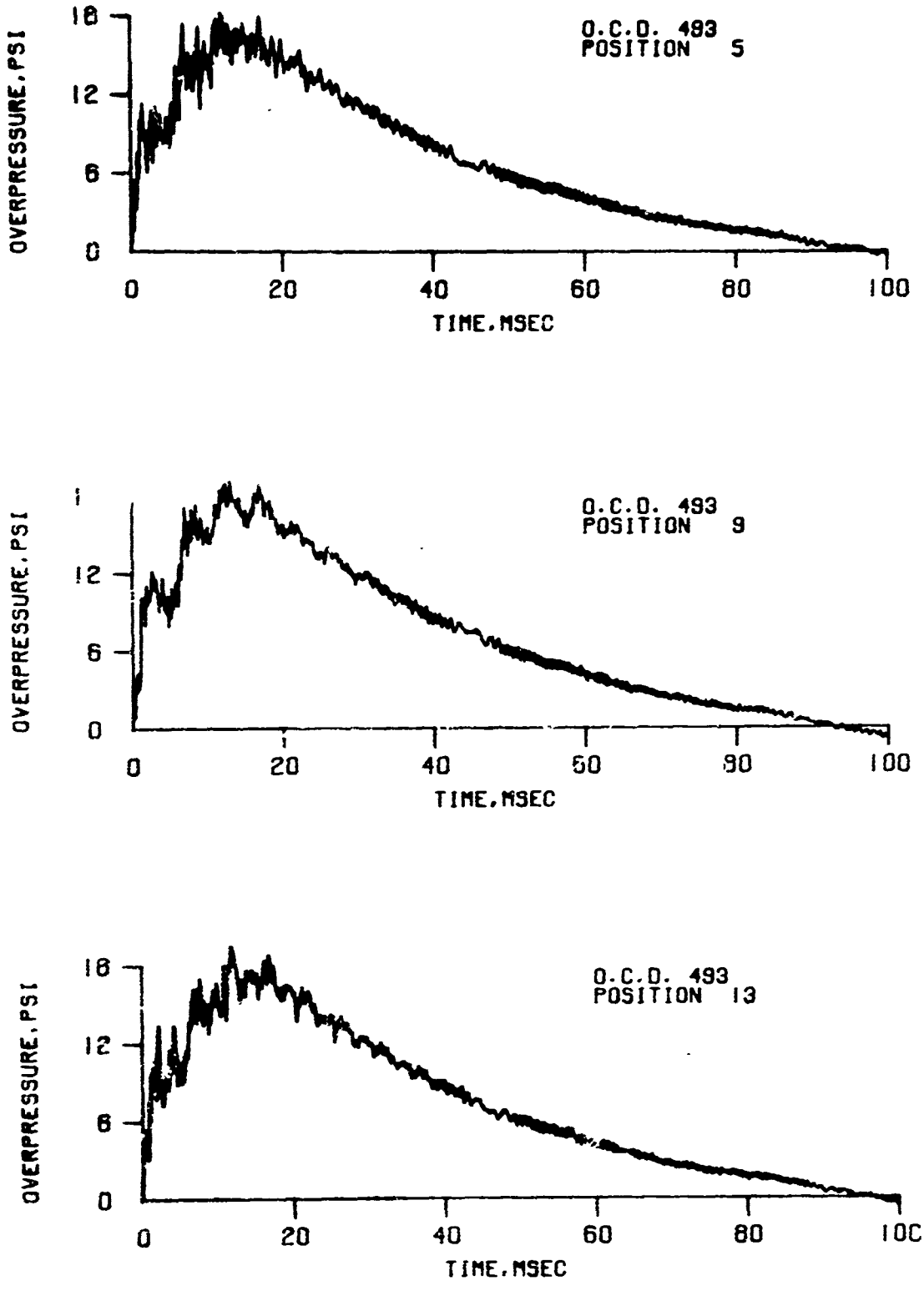
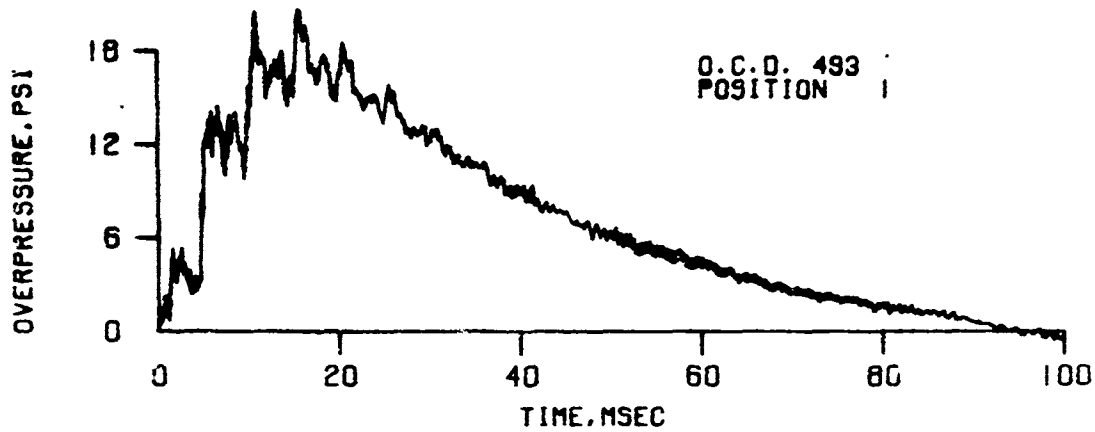


Figure B-7. (Continued)



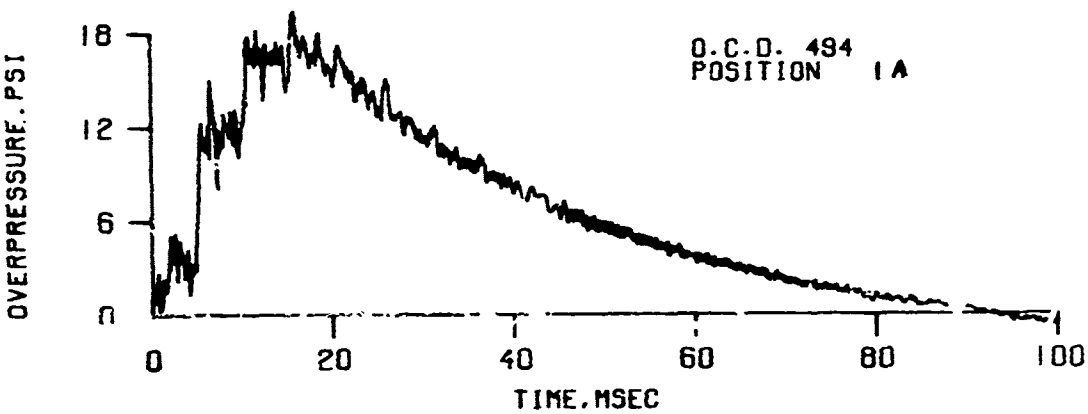


Figure B-7. (Continued)

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APPENDIX C

COMPUTER PROGRAM FOR PRESSURE FILL

USE OF APPENDIX C

The computer program for the prediction of the average pressure-time fill of a room is written in Fortran IV with slight modification for the BRL computer. The plotting routines are for the Calcomp Plotter. See ARDC Tech. Report No. 6, July 1970, Aberdeen Proving Ground, Md. 21005.

The input data are shown at the end of the program. In the order listed, they are: the area of the entrance (square feet) to the room, the volume of the room (cubic feet), a characteristic time (seconds) chosen to give a smooth filling curve, for example, about equal to (05) (Volume/Area)/(Ambient Sound Velocity), ambient pressure (psi) before the shock wave enters the room, and the density (slugs per cubic feet) of the input shock wave.

The second set of input data is made up of time (seconds) and pressure (psi) points from the input shock wave.

The third set of data (after the negative control card) is time (seconds) and pressure (psi) points from the experimental fill curve that is being compared. A negative control card separates sets of data.

The ambient density in the room before the shock wave enters is given on Line 31 of the program as D3. This value is changed as needed for new conditions.

Fill curve tables are printed out as a function of time and a plot is made which contains the input wave, the predicted fill curve, and the experimental data points.

```
*         7B175  FORTRAN CHAMBER FI L RAITY - COULTER  FEB 72                1
      LIST(CARDS)                                                            2
$         MAXT( 3) MIAS                                                      3
$      MAXO( 2000) INES                                                      4
       DIMENSION X(500),Y(500),TX(500),P2(500),T1(10),T2(10),T3(10),         5
      1YY(500)                                                               6
       COMMON BB(5000)                                                       7
1         FORMAT(=E12.6)                                                     8
2         FORMAT(=12,3,4E16.6)                                               9
3         FORMAT(80X)                                                       10
4         FORMAT(1X,5HAREA1,9X,6HVOLUME,12X,4HTIME,11X,8HPRESSURE,          11
     1    8X,7HDENSITY)                                                     12
5         FORMAT(1X,4HTIME,10X,8HPRESSURE,10X,4HDENS,13X,2HU2,              13
     1    13X,3HDDT)                                                        14
6         FORMAT(1X,7HSECONDS,10X,3HPSI,10X,8HUE-S2/F4,11X,3HFPS,           15
     1    12X,3HPSI)                                                        16
          G1=,714286                                                        17
          G2=,285714                                                        18
          G3=7.                                                             19
10        READ(5,*)A2,V3,T1,P30A,D1                                         20
          WRITE(6,3)                                                        21
          WRITE(6,4)                                                        22
          WRITE(6,2)A2,V3,T1,P30A,D1                                        23
          WRITE(6,3)                                                        24
          WRITE(6,5)                                                        25
          WRITE(6,6)                                                        26
          WRITE(6,3)                                                        27
          I=1                                                               28
          T=0.                                                              29
          P30=P30A*144.                                                     30
          D3=,002373                                                        31
          P3=P30                                                            32
       J=0                                                                  33
20        READ(5,*)RT,RP,A,B,C,H                                            34
          IF(RT.LT.0.0) GO TO 30                                            35
          X(I)=RT                                                           36
          X(I+1)=A                                                          37
          X(I+2)=C                                                          38
          Y(I)=RP                                                           39
           Y(I+1)=B                                                         40
           Y(I+2)=H                                                         41
           I=I+3                                                            42
          GO TO 20                                                          43
30        N=I+1                                                             44
          NN=N                                                              45
          I=1                                                               46
          DO 40 K=1,NN                                                      47
       YY(I)=Y(I)                                                           48
          Y(I)=Y(I)*144.+P30                                                49
40        I=I+1                                                             50
50        TA=T+TI                                                           51
          CALL DVDINT(T,PA,X,Y,NN,2)                                        52
          CALL DVDINT(TA,PB,X,Y,NN,2)                                       53
          P1=(PA+PB)/2.                                                     54
          D1T=((P1/Y(1))**G1)*D1                                            55
          IF(P1.GT.P3)GO TO 60                                              56
          P13=P1/P3                                                         57
       CM=0.915+0.4264*P13                                                  58
          US2=(G3*P3/D3)*(1.-P13**G2)                                       59
```

```
          UE=SQRT(UE2)                                                    60
      UE=CW*UE                                                            61
          DE=(P13**G1)*D3                                                 62
          RE=UE*DE*A2*TI                                                  63
          R3N=D3*V3-RE                                                    64
          D3N=R3N/V3                                                      65
          P3N=P3-(RE/V3)*(UE2/G3*P1/DE)                                   66
          U2=-UE                                                          67
          D2=DE                                                           68
          GO TO 70                                                        69
60        P31=P3/P1                                                       70
      CW=0.915+0.3454*P31                                                 71
      IF(P31.LT.0.528)GOTO 90                                             72
          U22=(G3*P1/D1T)*(1.-P31**G2)                                    73
      GOTO 91                                                             74
 90   U22=(0.833*P1/D1T)/31                                               75
 91   U2=SQRT(U22)                                                        76
      U2=CW*U2                                                            77
          D2=(P31**G1)*D1T                                                78
          R2=U2*A2*D2*TI                                                  79
          R3=D3*V3                                                        80
          R32=R3/R2                                                       81
          D3N=(R2+R3)/V3                                                  82
          P3N=D3N*(U22/G3+P3/D2+P3*R32/D3)/(1.+R32)                       83
70        T=T+TI                                                          84
          P3NA=(P3N-P30)/144.                                             85
          PDT=D2*U2*U2/289.                                               86
          WRITE(6,2)T,P3NA,D3N,U2,PDT                                     87
          P3=P3N                                                          88
          D3=D3N                                                          89
      CALL HOLD(T,P3NA,TX,P2,J)                                           90
          IF(T.LT.X(N))    GOTO 50                                        91
      CALL OUT(X,YY,TX,P2,J,N)                                            92
          GO TO 10                                                        93
      END                                                                93A
      SUBROUTINE DVDINT(X,FX,XT,FT,NP,ND)                        DDIN    94
          DIMENSION XT(1),FT(1),T(16)                            DDIN    95
          N=ND                                                   DDIN    96
 31       N1=(N-1)/2                                             DDIN    97
          N2=N/2                                                 DDIN    98
          N3=NP-N2+1                                             DDIN    99
          IF(NP-N)30,41,41                                       DDIN   100
 41       N4=N1+2                                                DDIN   101
          IF(XT(1)-XT(2))22,80,80                                DDIN   102
 22       CONTINUE                                               DDIN   103
         IF(X-2.*XT(1)+XT(2))20,20,21                            DDIN   104
 21       IF(X-2.*XT(NP)+XT(NP-1))42,42,20                       DDIN   105
 42       IF(X-XT(N4))45,43,43                                   DDIN   106
 43       IF(N4-N3)44,45,44                                      DDIN   107
 44       N4=N4+1                                                DDIN   108
          GOTO 42                                                DDIN   109
 45       N4=N4-1                                                DDIN   110
          N5=N4-N1                                               DDIN   111
          DO46I=1,N                                              DDIN   112
          T(I)=FT(N5)                                            DDIN   113
 46       N5=N5+1                                                DDIN   114
          L=(N+1)/2                                              DDIN   115
          TR=T(L)                                                DDIN   116
          N6=N4                                                  DDIN   117
          N7=N4+1                                                DDIN   118
```

```
            JU=1                                                          DDIN 119
            N2=N-1                                                        DDIN 120
             UN=1.0                                                       DDIN 121
            DO12J=1,N2                                                    DDIN 122
            N5=N4-N1                                                      DDIN 123
            N3=N-J                                                        DDIN 124
            DO9I=1,N3                                                     DDIN 125
            N8=N5+J                                                       DDIN 126
            T(I)=(T(I+1)-T(I))/(XT(N8)-XT(N5))                            DDIN 127
 9          N5=N5+1                                                       DDIN 128
            GOTO(10,11),JU                                                DDIN 129
 10         UN=UN*(X-XT(N6))                                              DDIN 130
            JU=2                                                          DDIN 131
            N6=N6-1                                                       DDIN 132
            GOTO 12                                                       DDIN 133
 11         UN=UN*(X-XT(N7))                                              DDIN 134
            JU=1                                                          DDIN 135
            N7=N7+1                                                       DDIN 136
            L=L-1                                                         DDIN 137
 12         TR=TR+UN*T(L)                                                 DDIN 138
            FX=TR                                                         DDIN 139
            RETURN                                                        DDIN 140
 20         PRINT50,X,XT(1),XT(NP)                                        DDIN 141
            STOP                                                          DDIN 142
 50         FORMAT(23H ARG. NOT IN TABLE  X= ,E14.7,9H  XT(1)= ,          DDIN 143
     1      E14.7,10H  XT(NP)= ,E14.7,6H  DDIN)                           DDIN 144
 30         PRINT51,NP,ND                                                 DDIN 145
 51       FORMAT(22H TABLE TOO SMALL  NP= ,I5,6H  ND= ,I5,6H  DDIN)       DDIN 146
            STOP                                                          DDIN 147
 60         IF(X-2.*XT(1)+XT(2))61,20,20                                  DDIN 148
 61         IF(X+2.*XT(NP)+XT(NP-1))20,72,72                              DDIN 149
 72         IF(X-XT(N4))73,73,45                                          DDIN 150
 73         IF(N4-N3)74,45,74                                             DDIN 151
 74         N4=N4+1                                                       DDIN 152
            GOTO 72                                                       DDIN 153
 80         PRINT 52 ,XT(1)                                               DDIN 154
            STOP                                                          DDIN 155
 52         FORMAT(23H CONSTANT TABLE XT(1)= ,E14.7,6H  DDIN)             DDIN 157
*           LIST                                                             158
       END                                                                   159
C                                                                            160
*      COMPILE DISC, LABEL=ALL                                               161
C                                                                            162
       SUBROUTINE OUT(X,Y,T,P2,J,NN)                                         163
       DIMENSION X(5000),Y(5000),T (5000),P2(5000),T1(10),T2(10),T3(10)      164
       COMMON BB(50000)                                                      165
       NT=J$ J=0                                                             166
    50 FORMAT('CHAMBER FILL - BRL',1H>)                                      167
    51 FORMAT('PRESSURE - PSI',1H>)                                          168
    52 FORMAT('TIME - SECOND',1H>)                                           169
       CALL PLTCCB(16.0,1,BB(1),BB(5000))                                    170
       ENCODE(100,50,T1)                                                     171
       ENCODE(100,51,T2)                                                     172
       ENCODE(100,52,T3)                                                     173
       YNN=Y(NN)$ Y(NN)=0.0                                                 173A
       CALL FIXSCA(Y(1),NN,6.0,PS,PMIN,PMAX,PIN)                             174
       Y(NN)=YNN                                                            174A
       CALL FIXSCA(T(1),NT,12.0,TS,TMIN,TMAX,TIN)                            175
       CALL PLTCCS(2.0,10.0,TMIN,PMIN,TS,PS)                                 176
       CALL PLTCCD(1.0,T(1),P2(1),NT,0,TMIN,TMAX,PMIN,PMAX)                  177
```

```
      CALL PLTCCD(4.0,X(1),Y(1),NN,0,TMIN,TMAX,PMIN,PMAX)                    178
      CALL PLTCCA(TIN,PIN,TMIN,TMAX,PMIN,PMAX,0)                             179
      XT=TMIN-YS*0.8$ YT=PMIN+PS*2.5                                         180
      CALL PLTCCT(0.1,T2(1),1.0,0.0,XT,YT)                                   181
      XT=TMIN+TS*5.0$ YT=PMIN-PS*0.6                                         182
      CALL PLTCCT(0.1,T3(1),0.0,1.0,XT,YT)                                   183
      XT=TMIN+TS*3.$ YT=PMAX+PS*0.25                                         184
      CALL PLTCCT(0.2,T1(1),0.0,1.0,XT,YT)                                   185
      DX=TIN                                                                 186
      CALL LABELA(DX,PIN,TMIN,TMAX,PMIN,PMAX,1.0,1.0)                        187
      DO 25 M=1,NT$ P2(M)=0.0$ T(M)=0.0                                      188
 25   CONTINUE                                                               189
      DO 30 I=1,100,5                                                        190
      READ(5,300)T(I),P2(I),T(I+1),P2(I+1),T(I+2),P2(I+2),                   191
     1T(I+3),P2(I+3),T(I+4),P2(I+4)                                          192
 300  FORMAT(10(F8.0))                                                       193
      DO 28 IK=1,5$ JK=IK-1                                                  194
    9 IF(T(I+JK).T.0.0)GOTO 29                                               195
 28   CONTINUE$ GOTO 30                                                      196
 29   NT=I+JK-1$ GOTO 31                                                     197
 30   CONTINUE                                                               198
 31   IF(NT.EQ.0)GOTO 40                                                     199
      CALL PLTCCD(2.1,T(1),P2(1),NT,0,TMIN,TMAX,PMIN,PMAX)                   200
 40   CALL PLTCCP                                                            201
      RETURN                                                                 202
      END                                                                    203
C                                                                            204
      SUBROUTINE HOLD(T,P3NA,TX,P2,J)                                        205
      DIMENSION TX(500),P2(500)                                              206
      J=J+1$ TX(J)=T$ P2(J)=P3NA                                             207
      RETURN$ END                                                            208
*         DATA                                                               209
 .264E00     .3704E01    .25E-03     .149E02     .3349-02
 .0E00       .103E02     .14E-02     .107E02     .281E-02    .112E02
 .421E-02    .113E02     .561E-02    .113E02     .699E-02    .111E02
 .842E-02    .108E02     .982E-02    .102E02     .112E-01    .975E01
 .127E-01    .939E01     .14E-01     .91E01      .154E-01    .864E01
 .169E-01    .843E01     .182E-01    .814E01     .197E-01    .783E01
 .211E-01    .764E01     .253E-01    .676E01     .309E-01    .545E01
 .351E-01    .443E01     .407E-01    .321E01     .449E-01    .23E01
 .505E-01    .128E01     .547E-01    .68E00      .604E-01    .53E00
-1.0E-02
 0.0    0.0     .0014  1.59   .0028  2.63   .0042  4.14   .0056  5.02
 .007   5.97    .0084  6.78   .0098  7.75   .0112  8.44   .0126  8.88
 .014   9.10    .0154  9.10   .0168  8.91   .0162  8.61   .0197  8.19
 .00211 7.66    .0253  6.55   .0323  4.56   .0379  3.41   .0435  2.34
 .0505  1.28    .0533  0.95   .0561  0.61   .0590  0.38   .0604  0.28
-1.0

     PROB                                                                    219
```

APPENDIX D

HIGH SPEED PHOTOGRAPHS - MODEL 40

SHOT 521

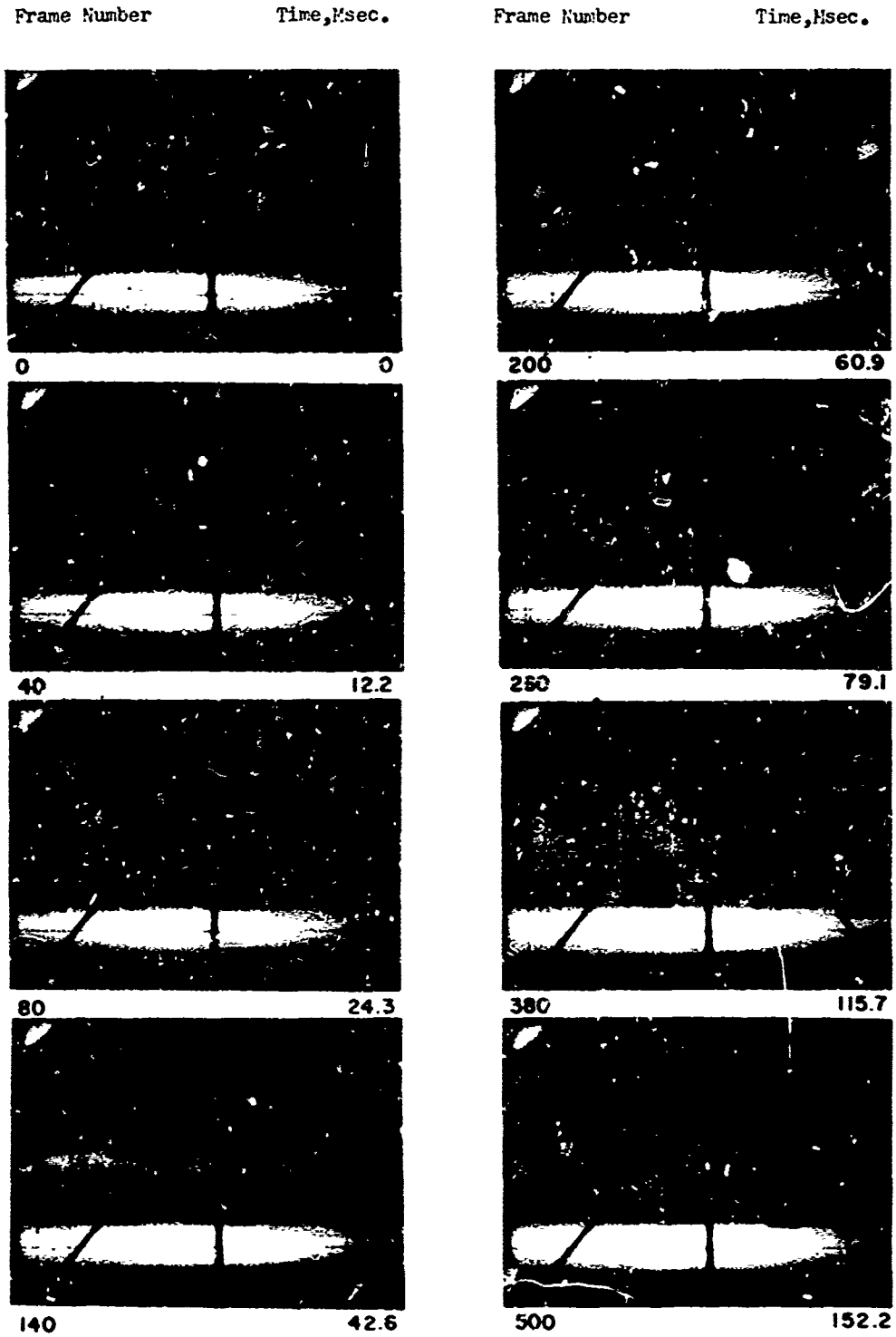

Figure D-1. Open Stairway-Cylinders Tied, Row 1 - 5.4psi

SHOT 507

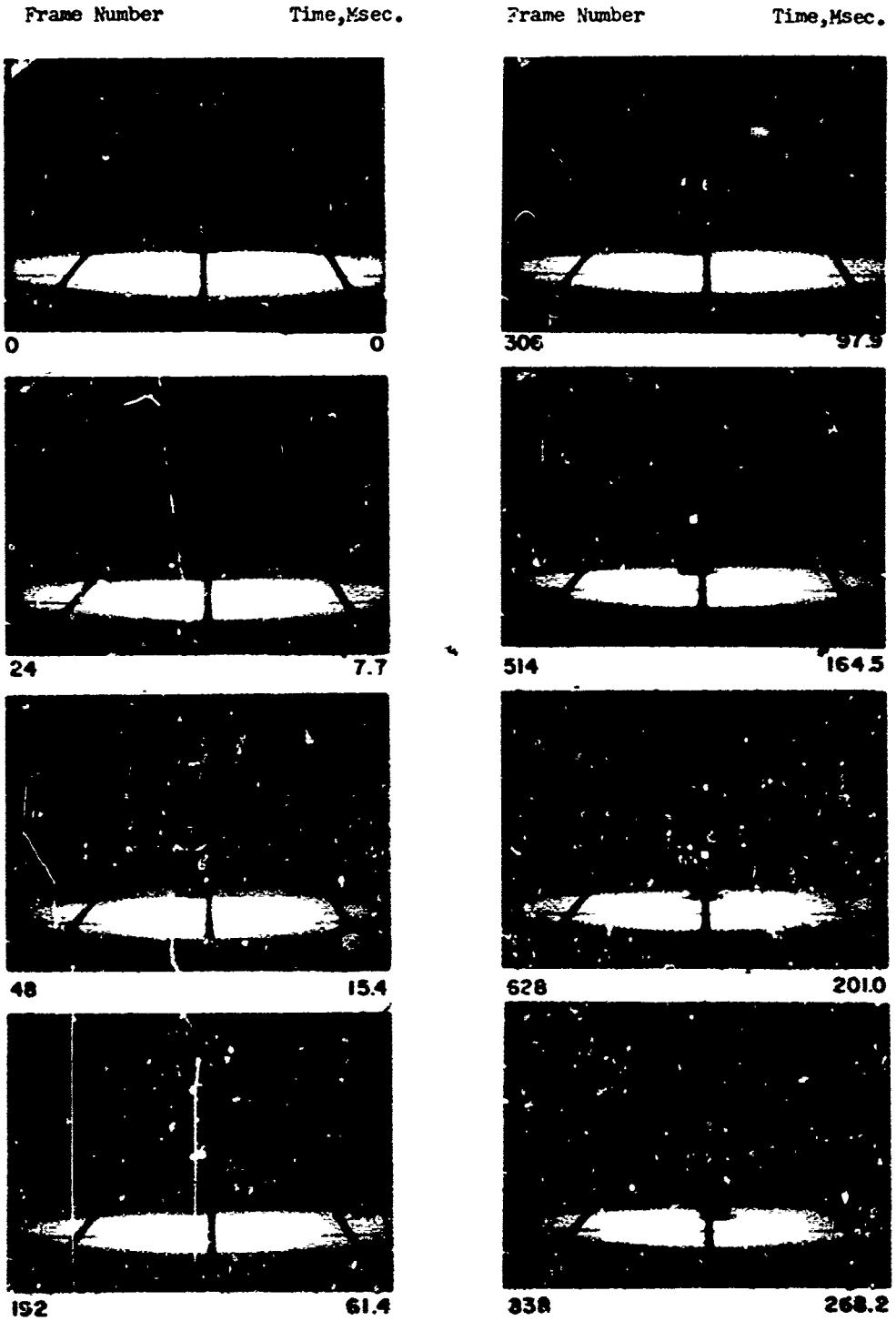

Figure D-2. Open Stairway- Cylinders on Row 1 - 20.3psi

SHOT 511

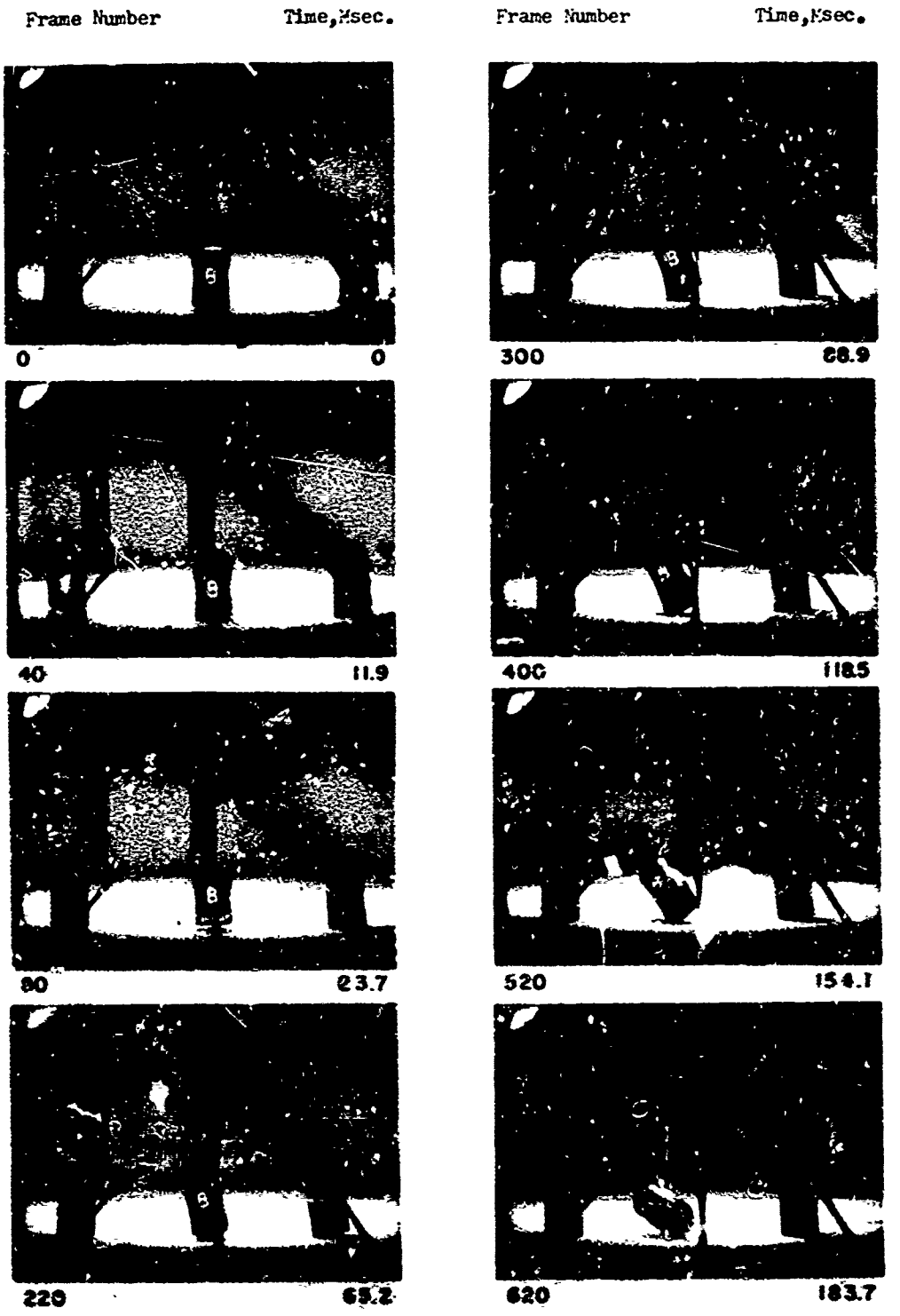

Figure D-3. Open Stairway-Cylinders on Row 4 - 10.2psi

SHOT 512

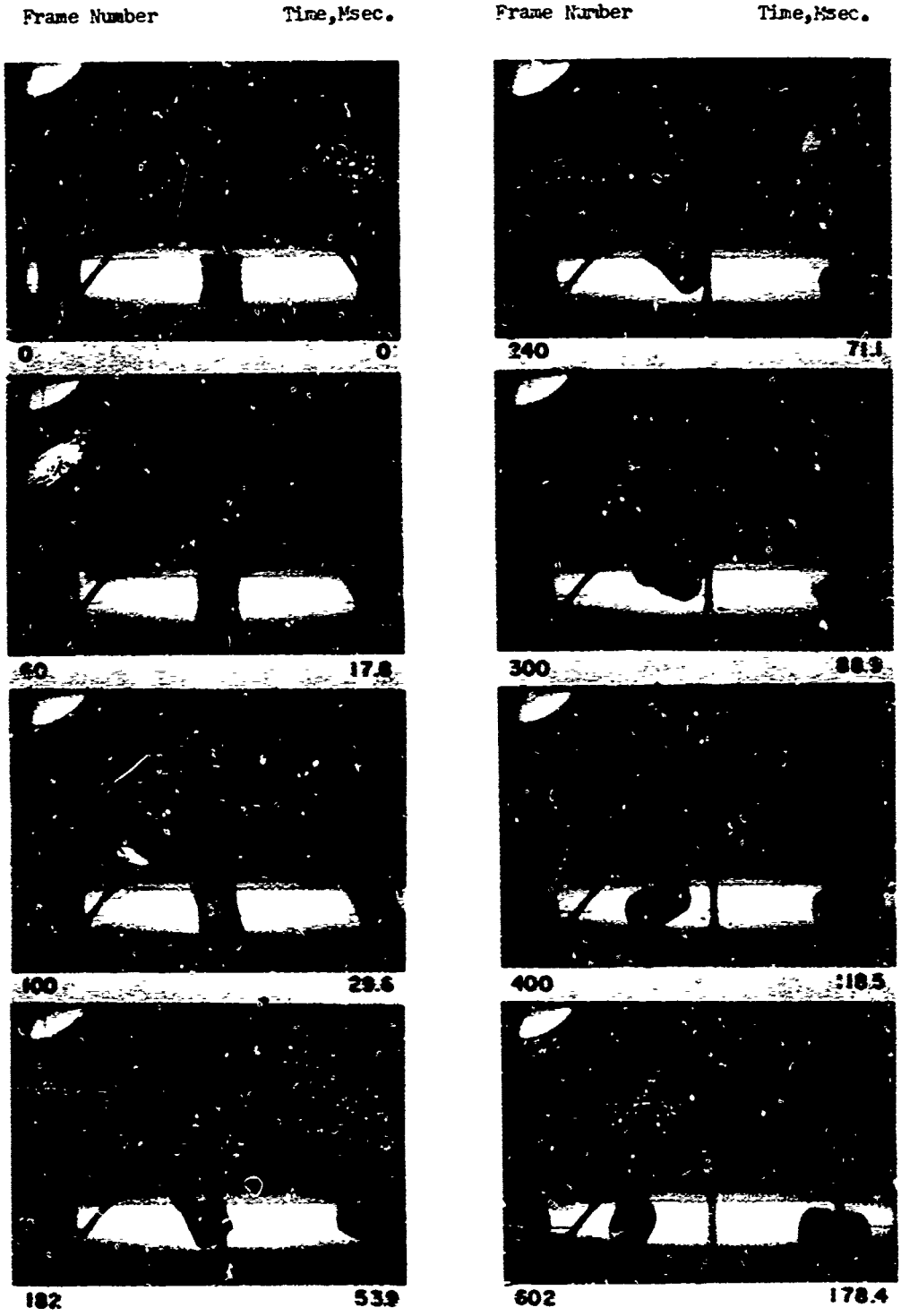

Figure D-4. Open stairway - Cylinders on Row 5 - 10.1 psi

SHOT 514

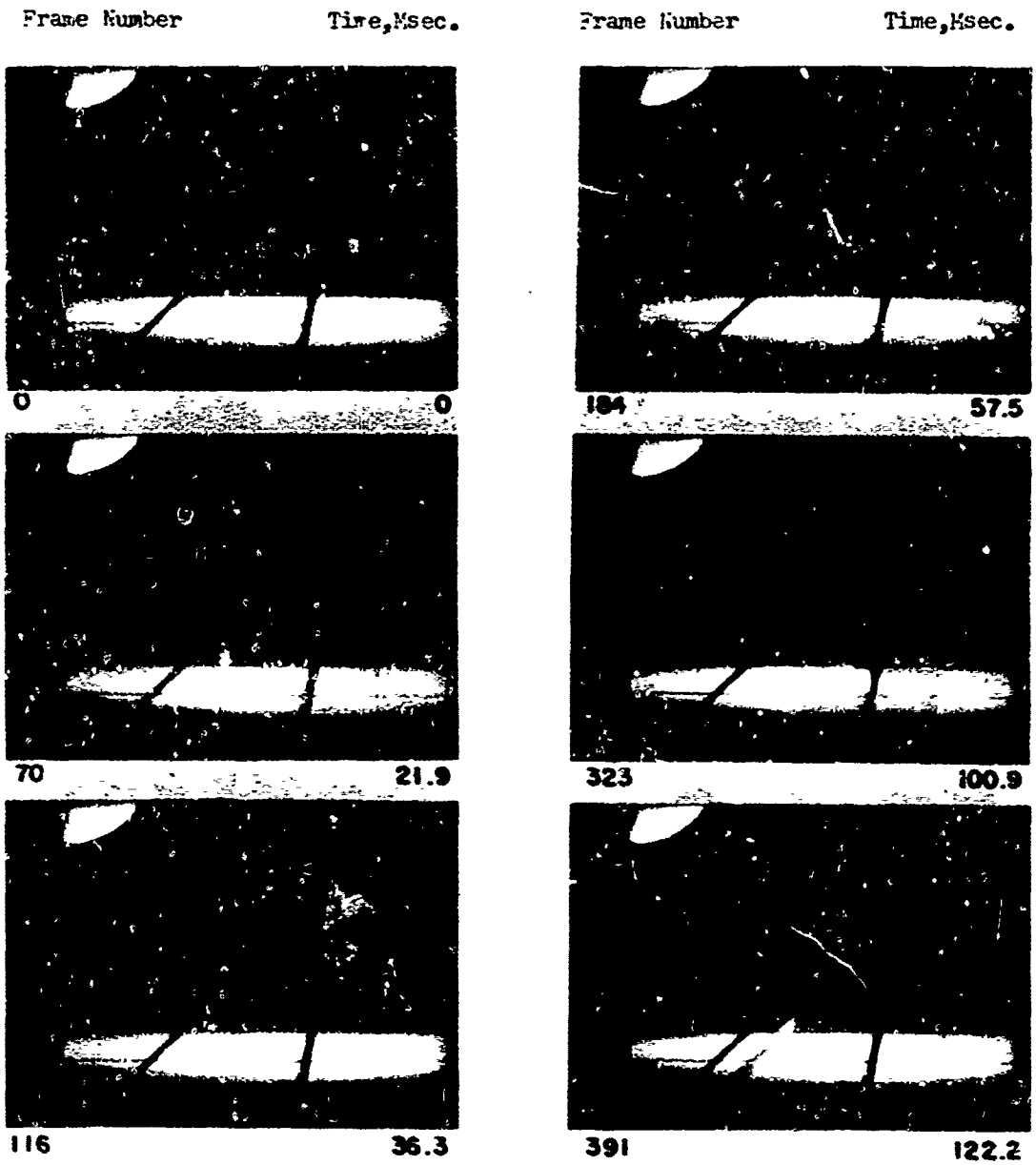

Figure D-5. Open Stairway-Pack Left Front - 10.3psi

SHOT 515

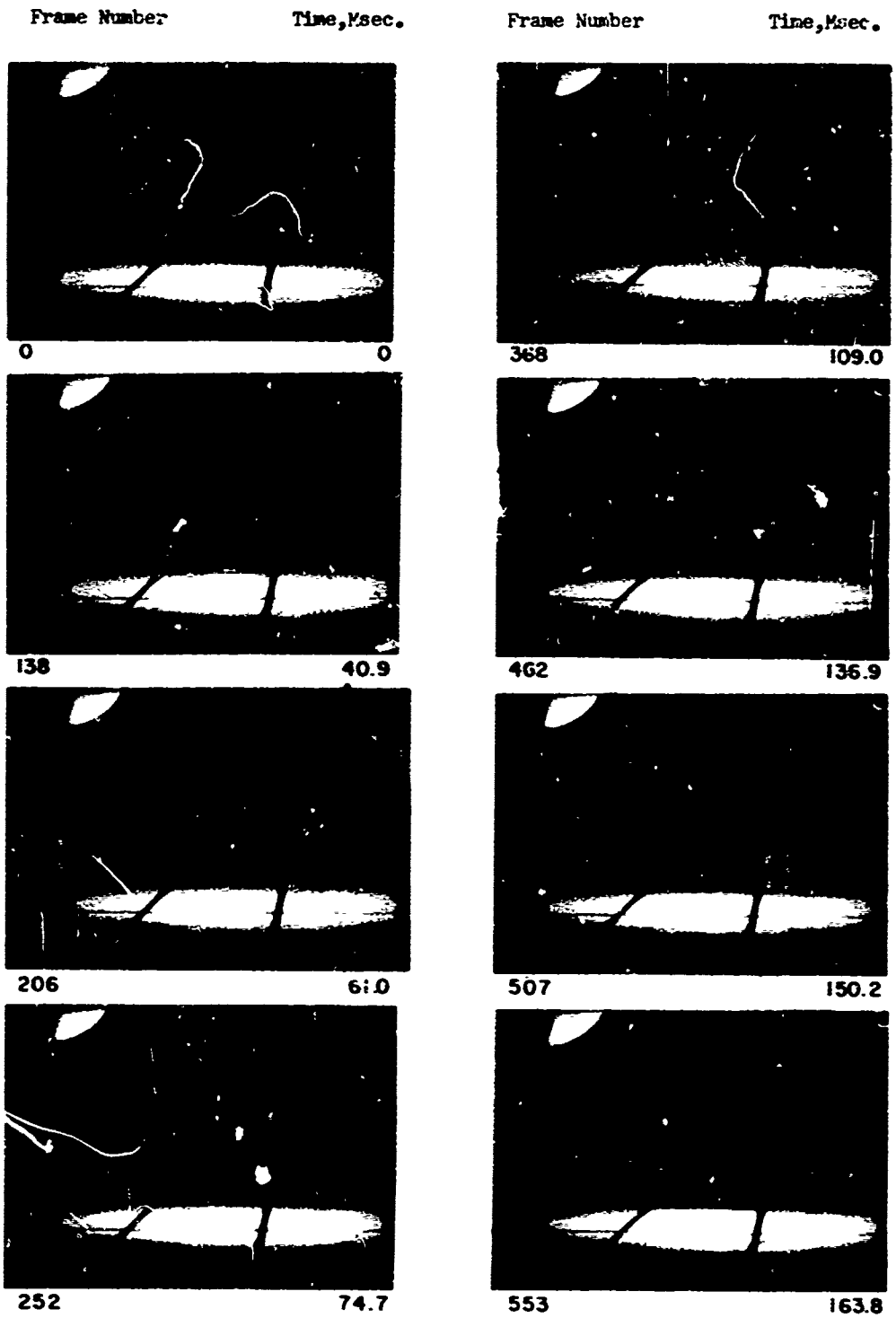

Figure D-6. Open Stairway-Pack Left Front - 20.5psi

SHOT 526

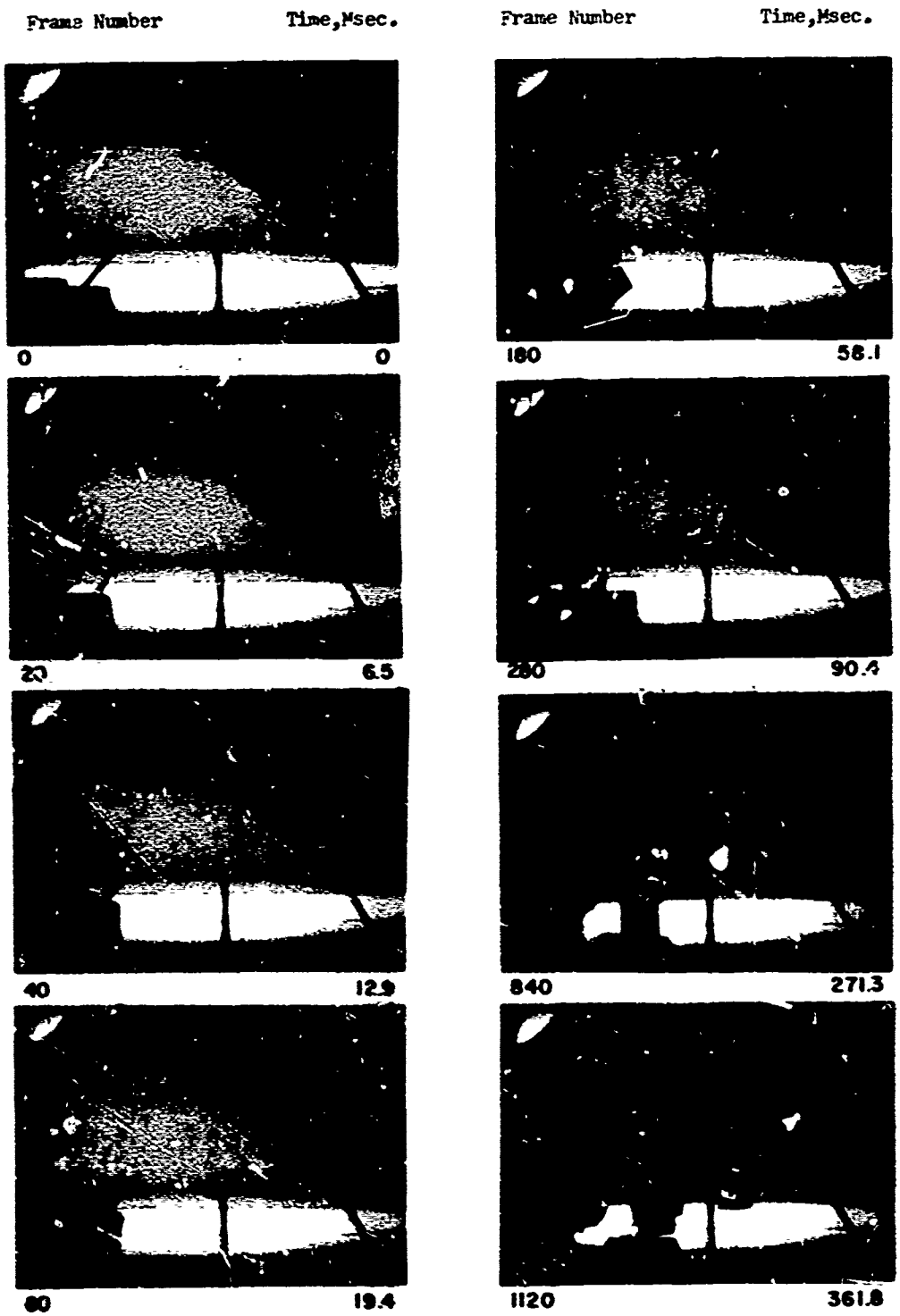

Figure D-7. Open Stairway-Pack Left Rear - 20.7psi

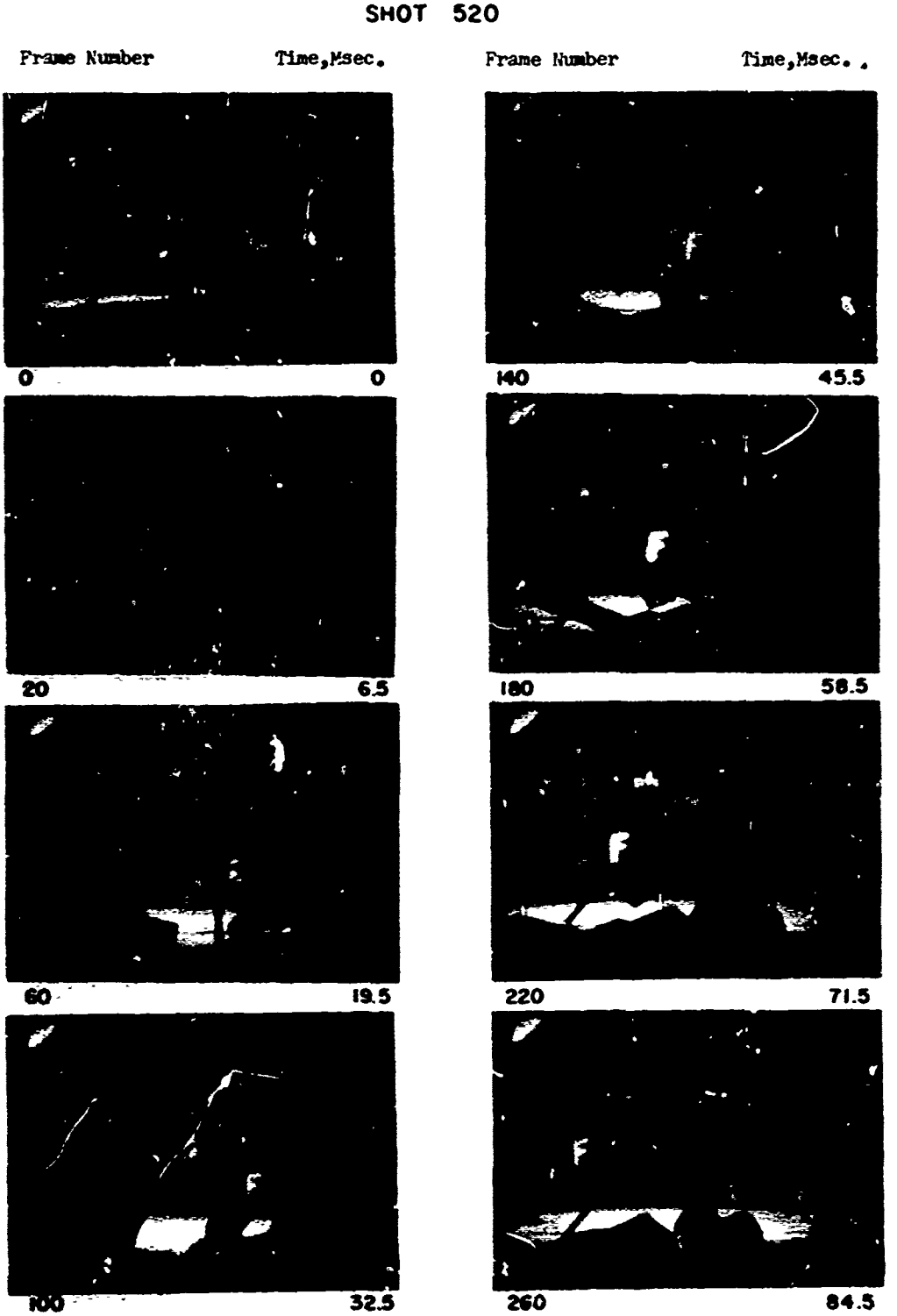

Figure D-3. Open Stairway-Pack at Rear - 2lpsi

SHOT 523

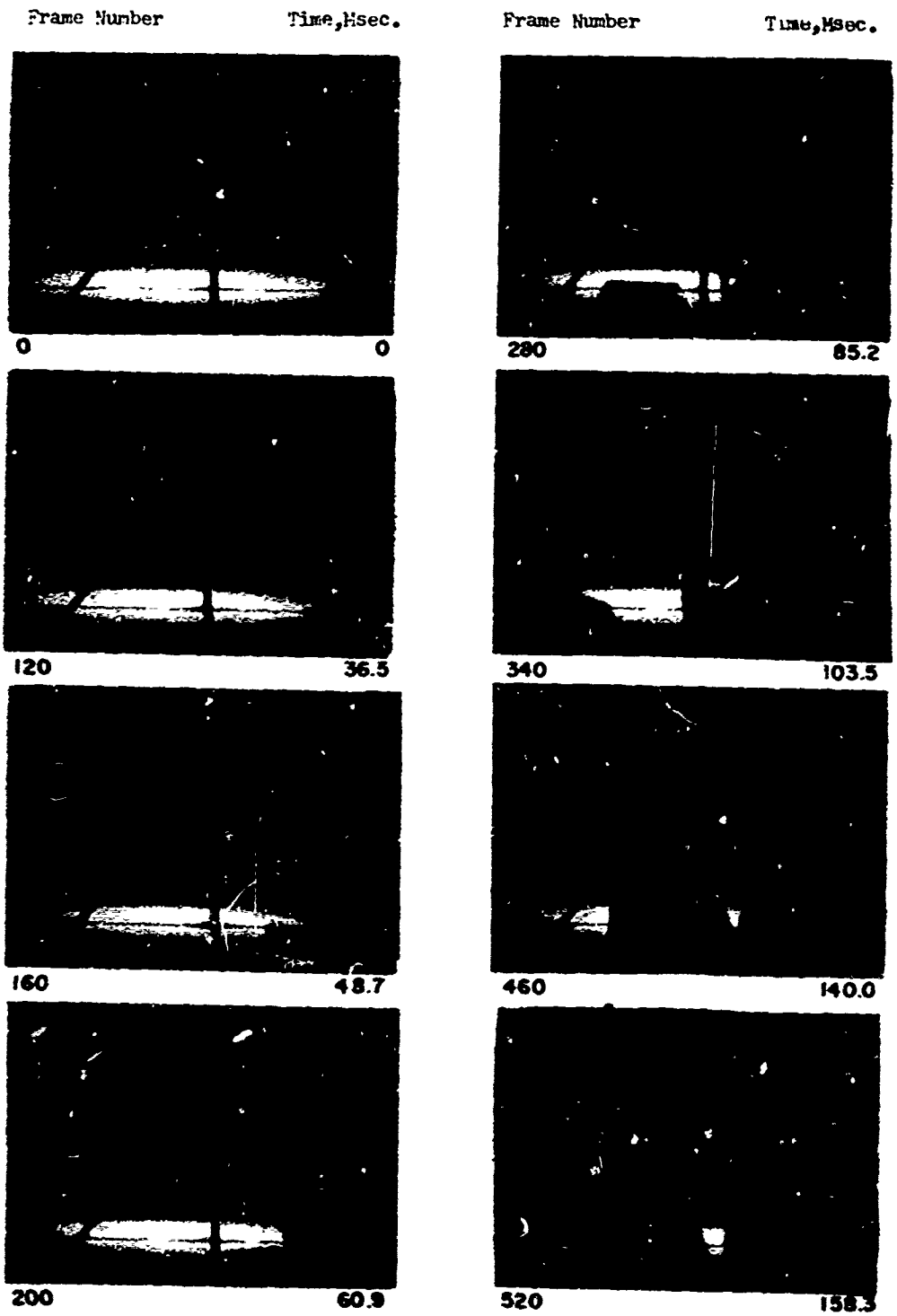

Figure D-9. Open Stairway-Pack at Right Rear - 10.5psi

SHOT 533

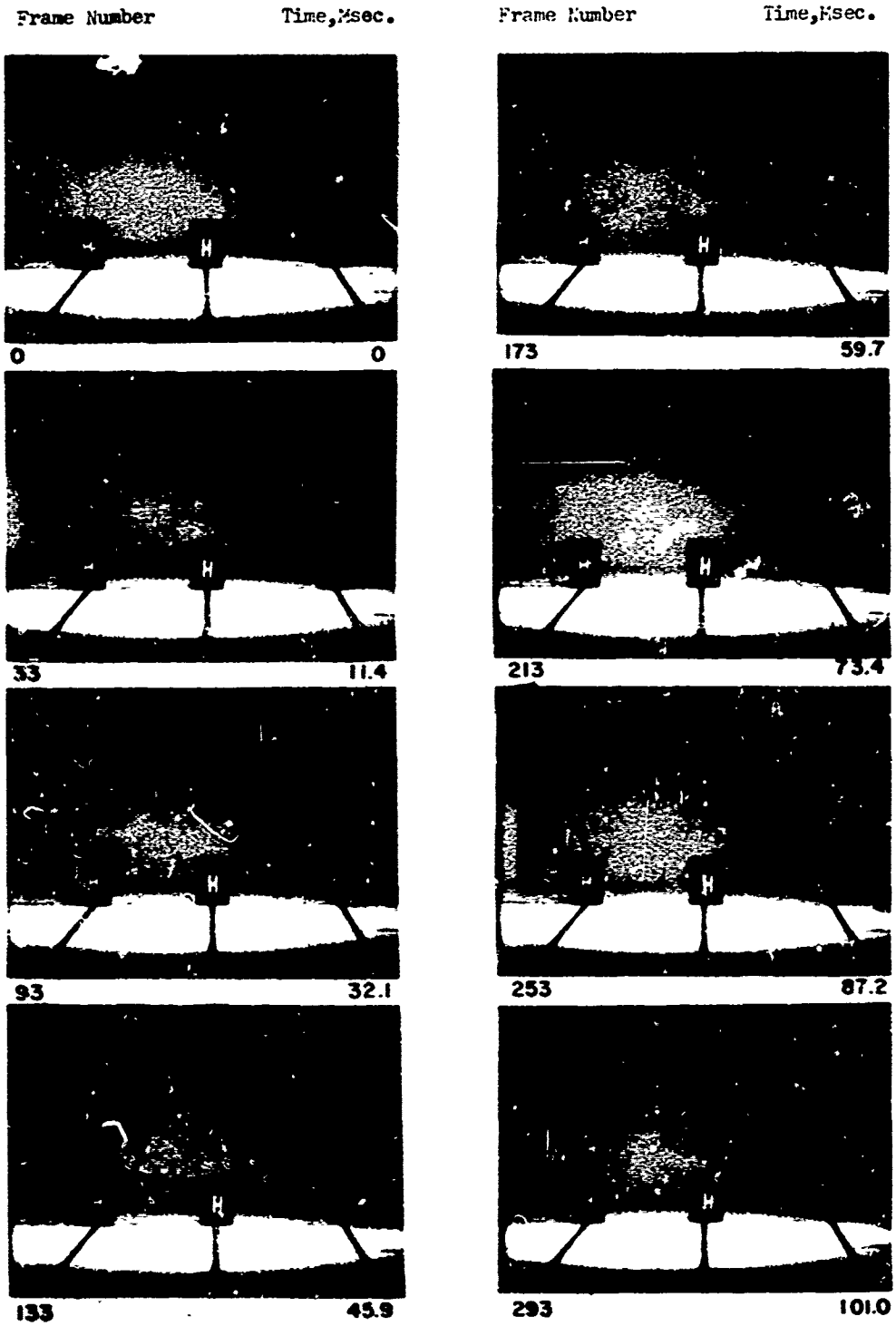

Figure D-10. Closed Stairway-Cylinders on Row 1 - 5.2psi

SHOT 534

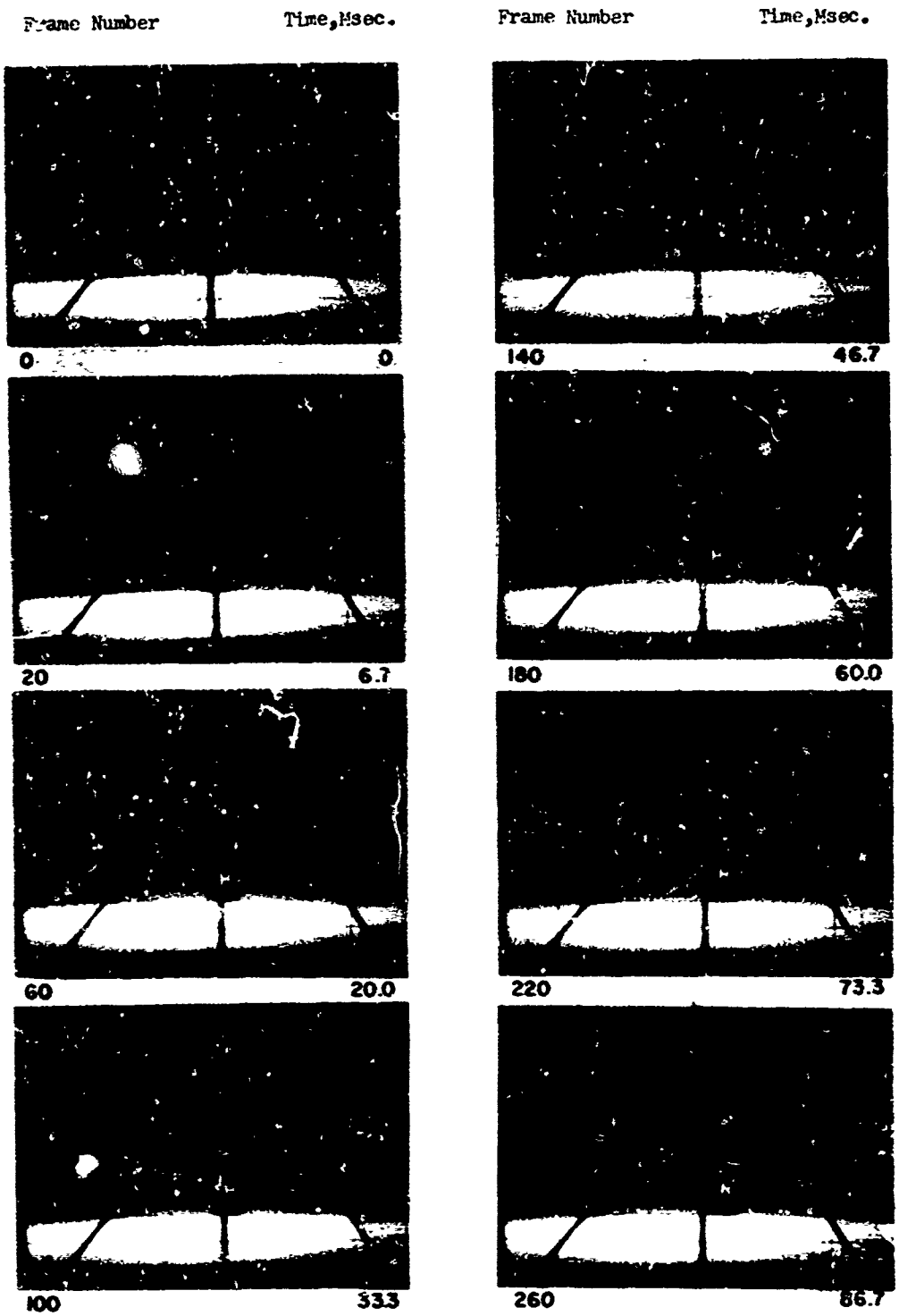

Figure D-11. Closed Fairway-Cylinders on Row 1 -- 10.2psi

SHOT 537

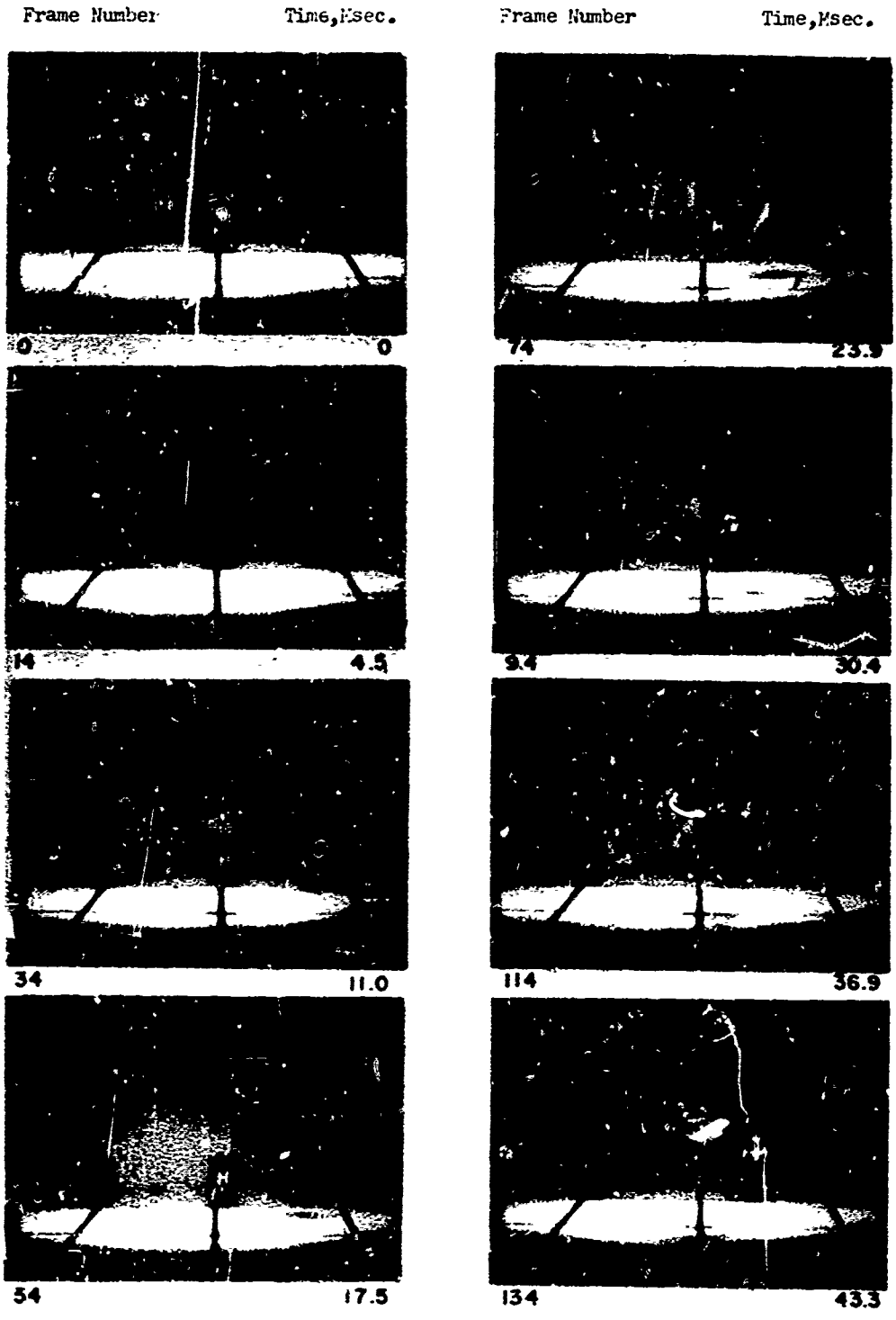

Figure D-12. Closed Stairway-Cylinders on Row 1 - 20.6psi

SHOT 537

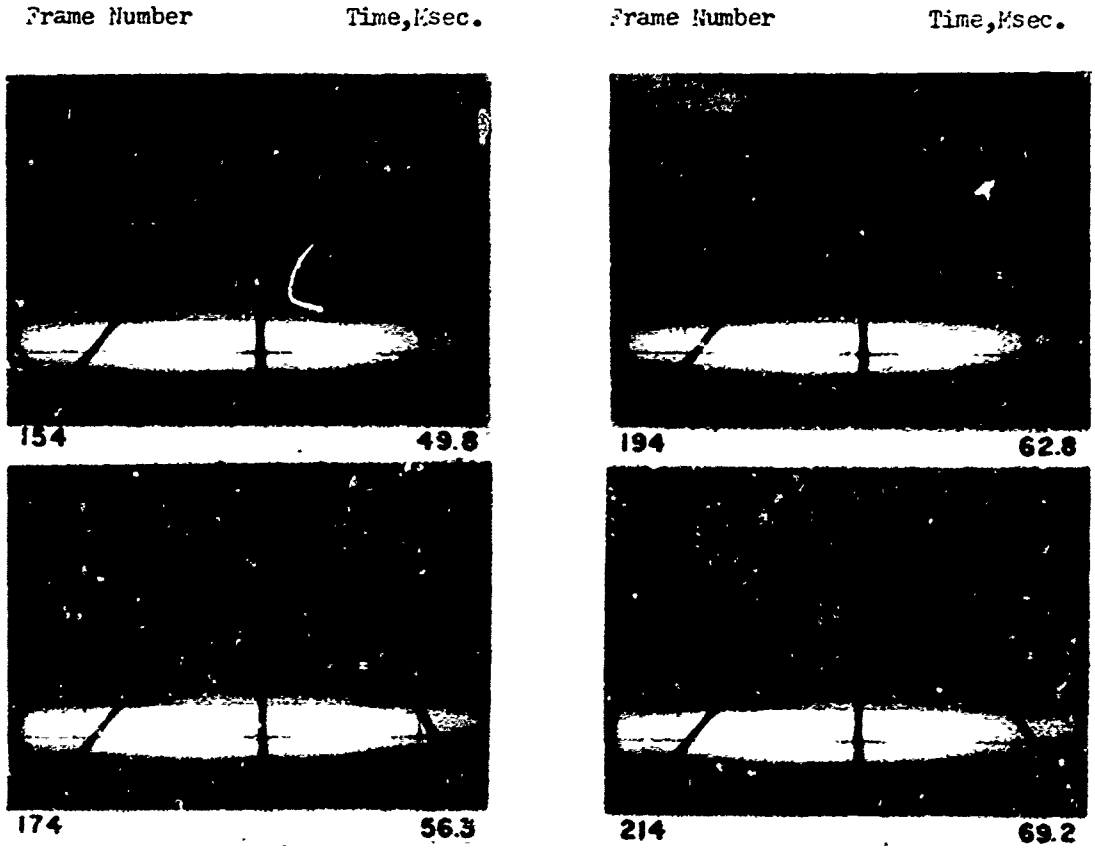

Figure D-12. (Continued)

SHOT 535

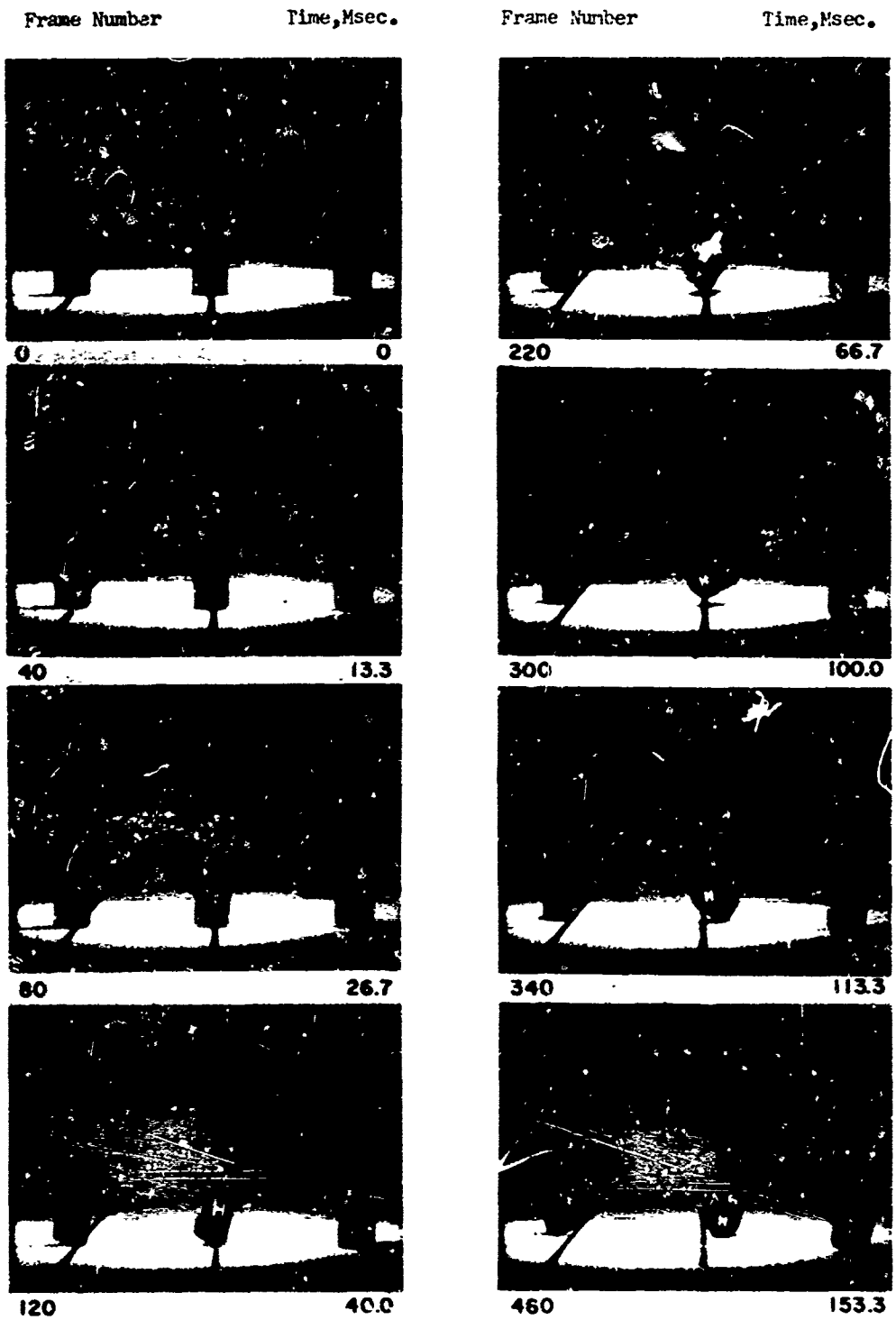

Figure D-13. Closed Stairway-Cylinders on Row 3 - 10.2psi

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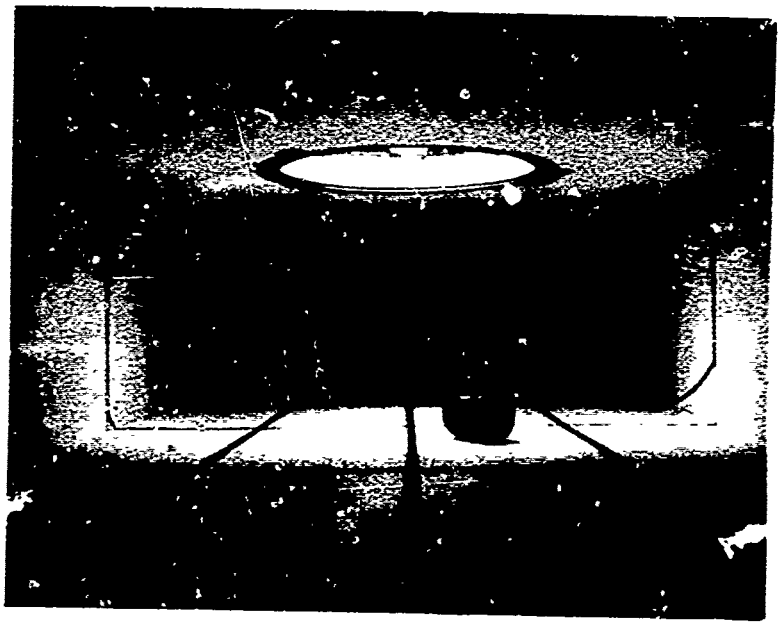
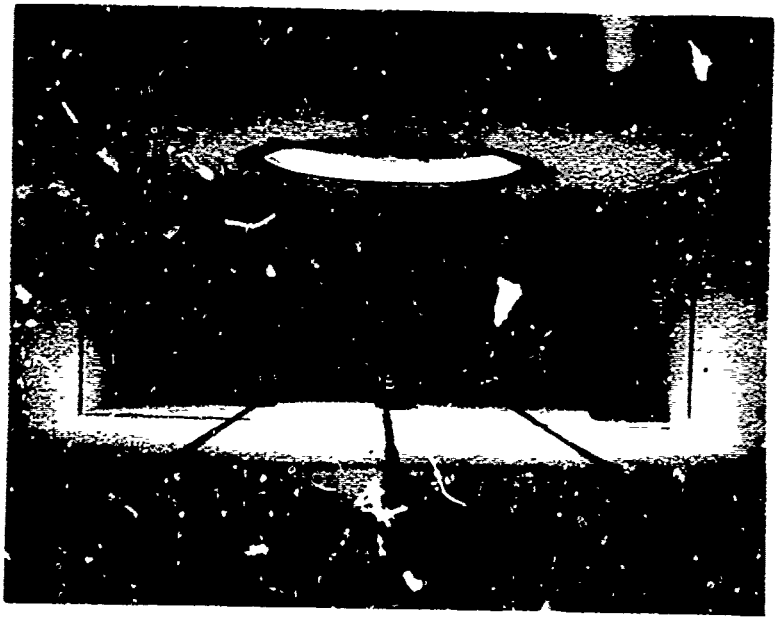
APPENDIX E

POST-SHOT PHOTOGRAPHS - MODEL 40



SHOT 505 ROW 1 5 PSI

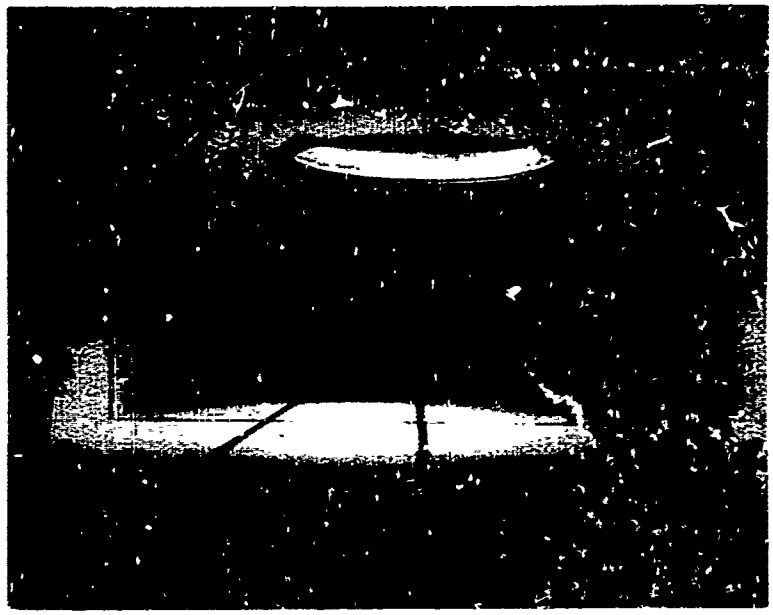
(A)



SHOT 508 ROW 2 5.3 PSI

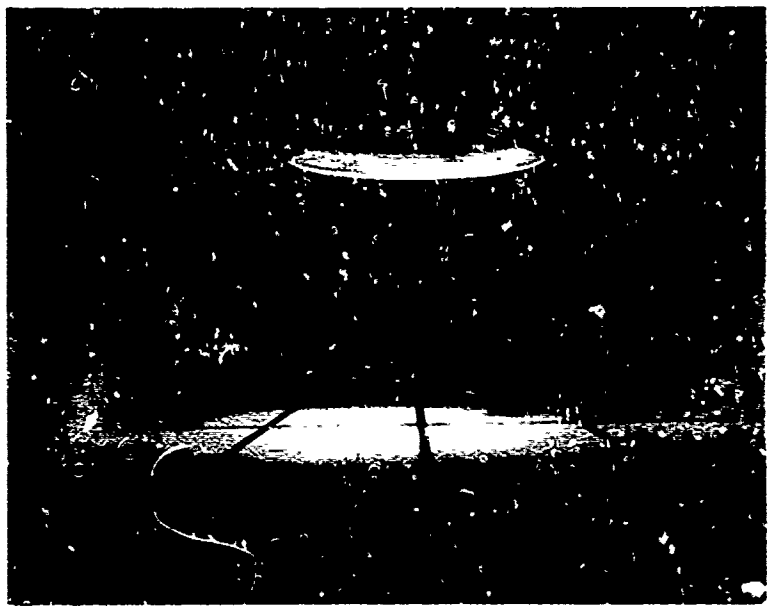
(B)

Figure B-1. Final Position of Cylinders - 5psi



PRE-SHOT 521 ROW 1

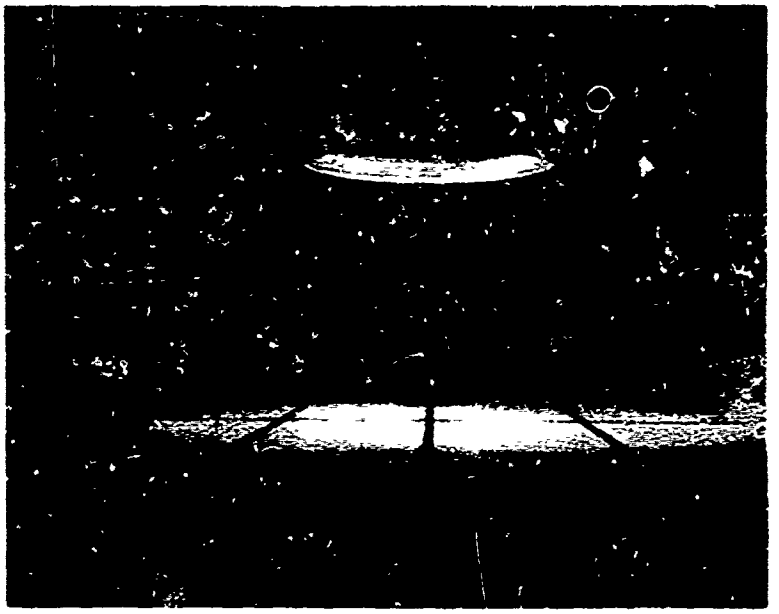
(C)



SHOT 521 ROW 1 5.4 PSI

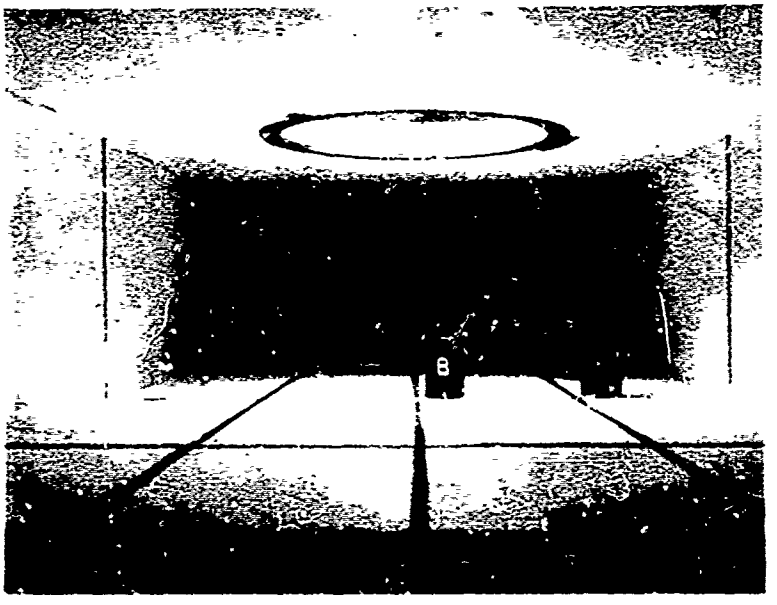
(D)

Figure E-1. (Continued)



SHOT 506 ROW 1 10.1 PSI

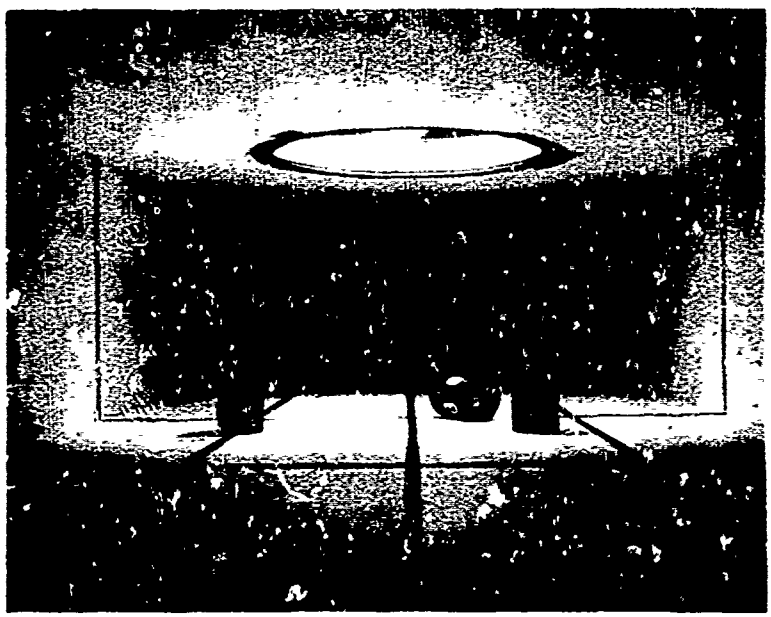
(A)



SHOT 510 ROW 3 10.3 PSI

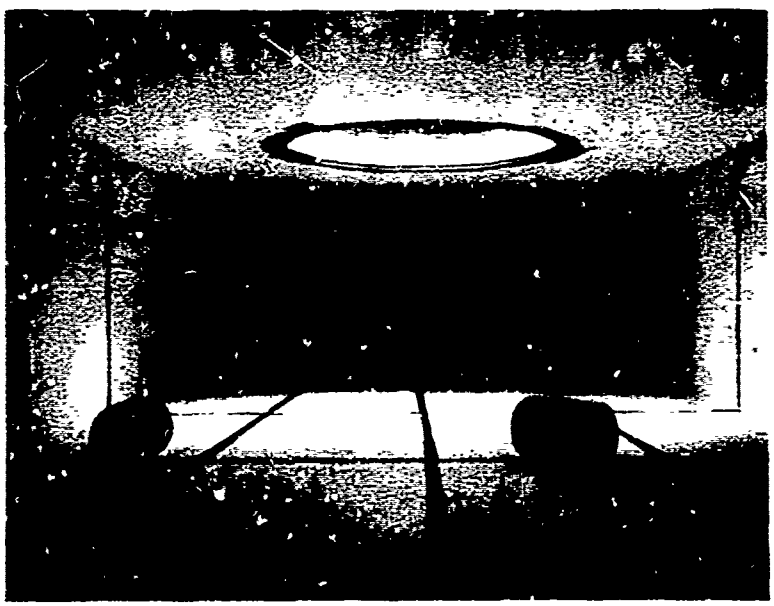
(B)

Figure E-2. Final Position of Cylinders - 10psi



SHOT 511 ROW 4 10.2 PSI

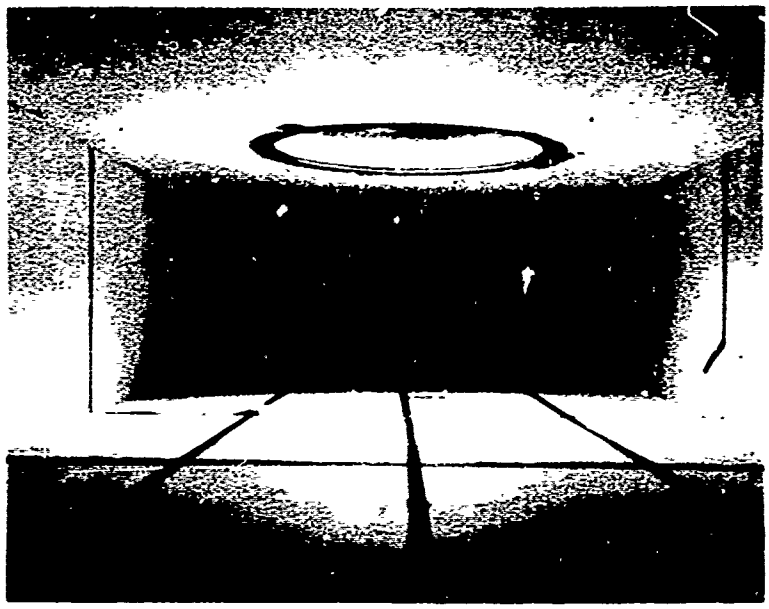
(C)



SHOT 512 ROW 5 10.1 PSI

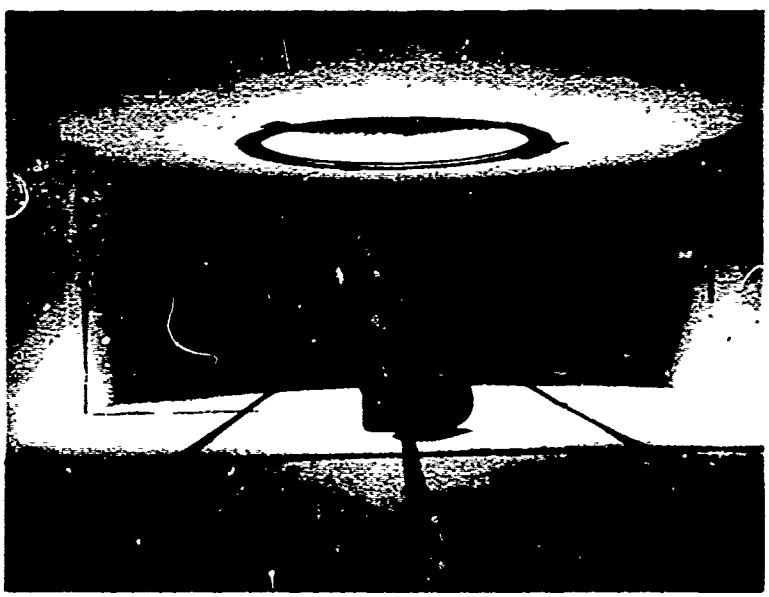
(D)

Figure E-2. (Continued)



SHOT 514 POSITION 1 10.3 PSI

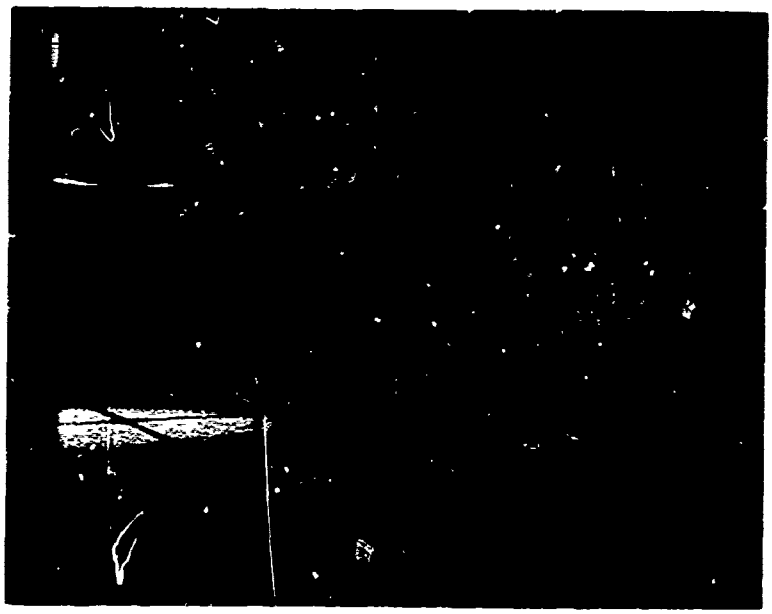
(A)



SHOT 515 POSITION 1 20.5 PSI

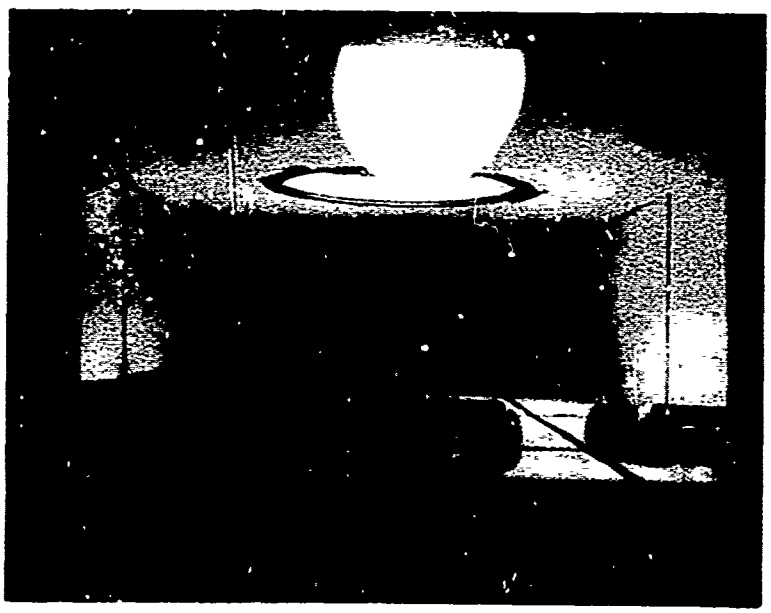
(B)

Figure E-3. Pack Started in Position 1



SHOT 522 POSITION 2 5.3 PSI

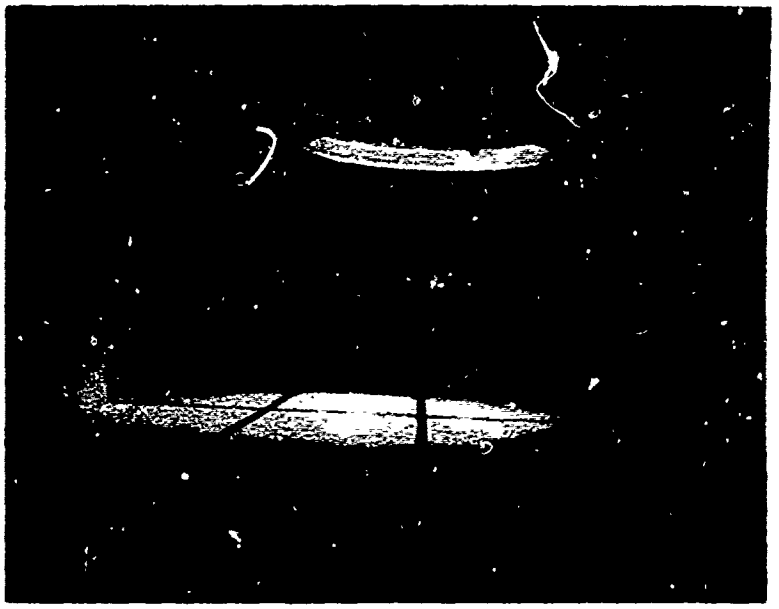
(A)



SHOT 523 POSITION 2 10.5 PSI

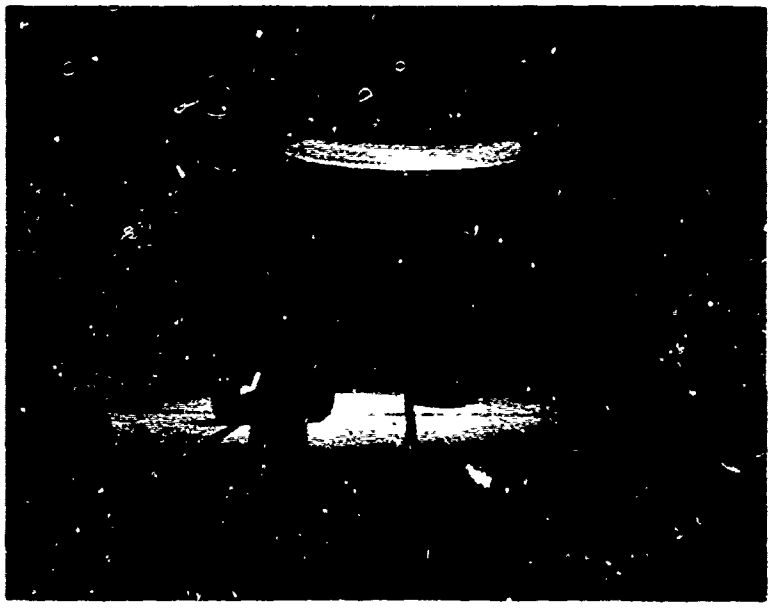
(B)

Figure E-4. Pack Started in Position 2



PRE-SHOT 519 POSITION 3

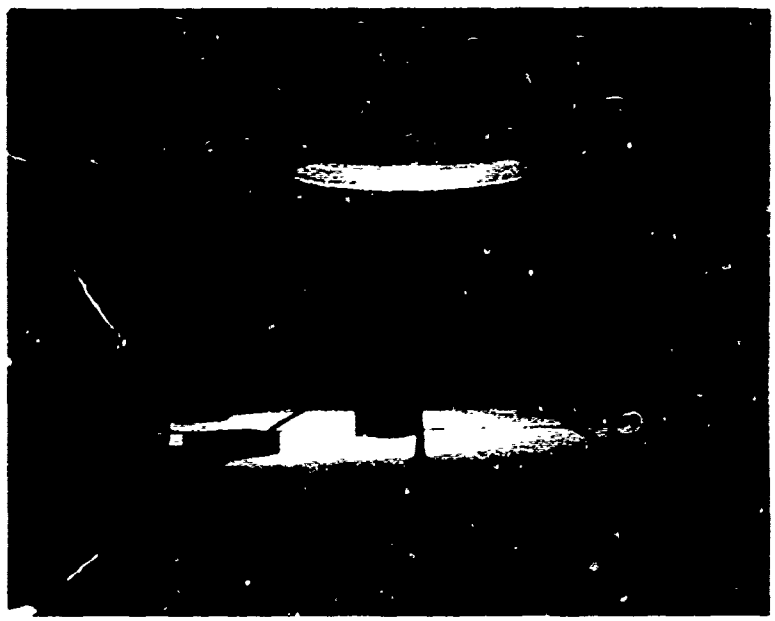
(A)



SHOT 519 POSITION 3 20.5 PSI

(B)

Figure E-5. Pack Started in Position 3

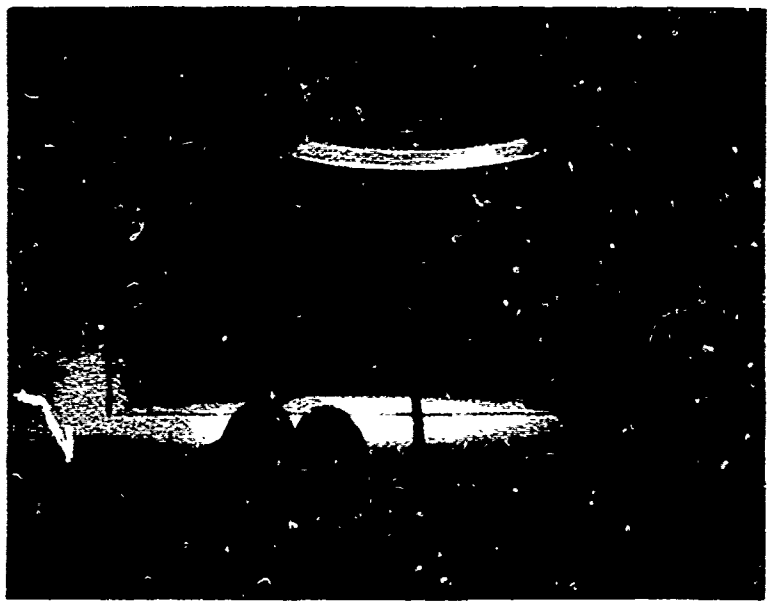


SHOT 520 POSITION 4 21.0 PSI

Figure E-6. Pack Started in Position 4

SHOT 517 POSITION 5 10.5 PSI

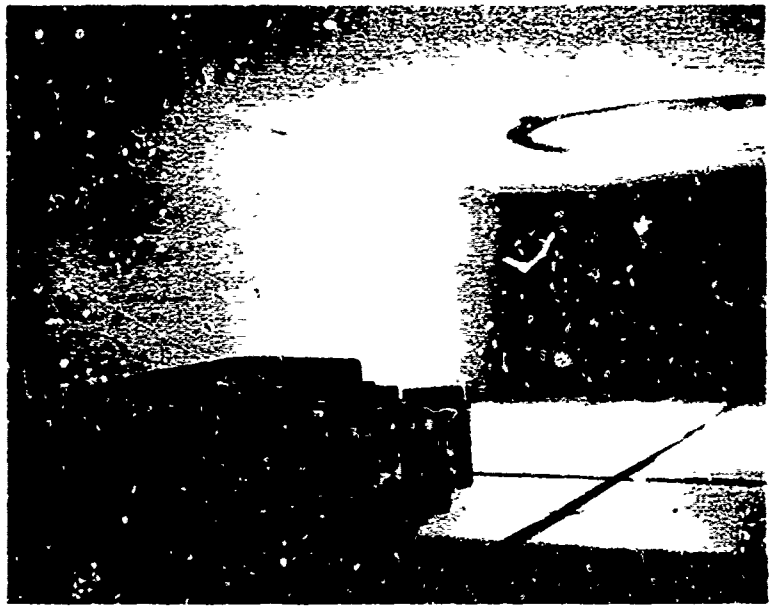
(A)



SHOT 518 POSITION 5 20.5 PSI

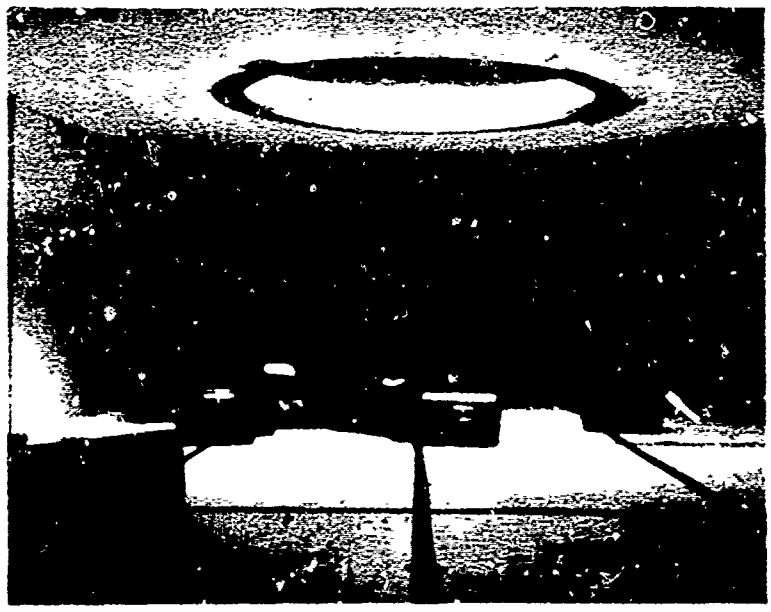
(B)

Figure E-7. Pack Started in Position 5



SHOT 525 POSITION 6 10.3 PSI

(A)



SHOT 526 POSITION 6 20.7 PSI

(B)

Figure E-8. Pack Started in Position 6

BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 2208

AUGUST 1972

SUMMARY
BLAST LOADING IN EXISTING STRUCTURES - BASEMENT MODELS

George A. Coulter

Terminal Ballistic Laboratory

Progress Report to Office of Defense Civil Prepardness Agency
Work Order No. DAHC 20-70-C-0310
Work Unit 1123C

ABERDEEN PROVING GROUND, MARYLAND

I. INTRODUCTION

The results are presented from a study of shock wave induced flows in the interior of a 1/12th scale basement model. The experiments were designed to simulate the flows and loading within a 100 person basement shelter when the above ground floors have been removed by the incoming blast wave.

II. EXPERIMENTS

The 1/12th scale basement model was mounted beneath the BRL 24 inch shock tube. The shock waves of input pressures 5, 10 and 20 psi were directed down the connected stairway, into the interior. Pressure transducers were mounted in the floor and in probes mounted two inches off the floor to record the interior pressures. During a second phase of the experiments, the probes were removed and small objects were placed inside the model. High speed photography was then used to observe the motion of objects under the effect of the internal flows.

III. RESULTS AND CONCLUSIONS

The appendixes of the report contain a summary of the shots, pressure-time records, and selected frames from the high speed films.

The following major pressure-time records were recorded within the interior of the model.

A. A low pressure vortex dip near the stairway was observed.

B. A generally smooth pressure filling curve was observed near the center area of the floor.

C. Multiple pressure peaks were observed superimposed on the general filling curve when the transducer positions were near walls.

A comparison of the high speed pictures shows a general small object rotation around the interior in a clockwise direction (for the model-shock wave orientation used). Velocity components across the floor

ranged from values of 4-14 ft/sec initially at the front to lower values of 1-2 ft/sec for greater times after the interior was filled with pressure.

Work now in progress include the addition of a side window to the present model to observe lengthwise motion along the room. A new model is being designed to simulate a 1000 shelter size basement.